Background Report: Integrated Ecological Impact Assessment

Climate Change and BC's Forest and Range Ecosystems

Final Draft

Prepared for:

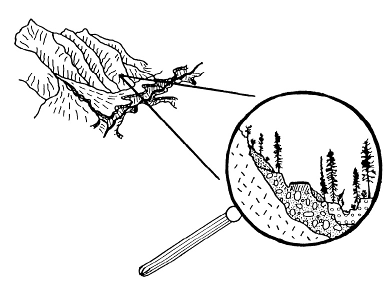
Future Forest Ecosystem Initiative
Research Branch, B.C. Forest Service

Prepared by:

G.F. Utzig, MSc, P.Ag.
R.F. Holt, PhD., R.P.Bio.
March 5, 2009

"We have options, but past is not one of them"
Sauchyn and Kulshreshtha 2008, p.295

"Times have changed –
no longer is our goal sustainable development
…. our goal must now be sustainable survival"
Blackstock 2008, p.15



Kutenai Nature Investigations Ltd. ***Veridian Ecological Consulting Ltd.***

Nelson, BC CANADA E-MAIL: g13utzig@telus.net rholt@veridianecological.ca

Executive Summary

This report is an assessment of the potential interactions between rapid climate change and forest and range ecosystems of British Columbia and related ecological impacts. It is an initial step in the development of an integrated vulnerability assessment for ecological and social systems. A preliminary discussion of potential management responses is also provided as a prelude to planning adaptation and mitigation policies and actions,

Recent reports by the International Panel on Climate Change (IPCC) have confirmed that global climate change is underway and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas (GHG) emissions. Analysis of climate data collected over the last century has confirmed that parallel climatic changes are also occurring in BC. Depending on assumptions about future GHG emissions, results from downscaled global climate models illustrate a range of potential climate changes that may occur in BC over the next century. These include increases in annual temperatures and precipitation, decreases in summer precipitation in southern BC, decreases in snowpack, increases in annual climate variability and increases in the frequency and magnitude of extreme weather events.

The impacts of recent climatic changes on forest and range ecosystems in BC are already becoming evident. The impacts occur directly through changes in the components of ecosystems themselves, both biotic (e.g., speciesôbehaviours - migration patterns, survival rates, changes in decomposition rates), and abiotic (e.g., decreased water availability, melting of permafrost). Impacts on ecosystems can also occur indirectly through climate change-induced changes to geomorphic and hydrologic processes (e.g., increased landslide frequencies and channel instability, loss of glaciers), or changes to disturbance mechanisms (e.g., increased frequency and severity of fires and windthrow). Any of these individual changes can also disrupt the complex interactions between ecosystem components leading to cascading effects (e.g., changes to pest-host, predator-prey, herbivore-forage relationships).

The exposure to climate change is predicted to be greatest in the Northern Interior of the province. In that region, the largest temperature increases in BC are expected to be accompanied by year-round increases in precipitation in the west central portion, and winter increases in the eastern Peace River area. Alpine ecosystems of the Northern Interior are predicted to eventually disappear as upper elevation conditions become more suitable for trees and shrubs. Increases in regional summer temperatures may result in increased frequency and size of fires, especially where fuel loadings have been affected by insect outbreaks (e.g., spruce bark beetle and mountain pine beetles have become recently active in the Yukon). Lakes and rivers will freeze later in the autumn and thaw earlier in the spring, affecting aquatic habitats and terrestrial migration routes. Warmer water temperatures may increase aquatic productivity in some cases, but the potential effects on arctic fish species are largely unknown. Permafrost melting will affect soil processes, thereby increasing localized instability and potentially reducing water quality.

Ecosystems in the Central Interior have already seen significant impacts due to changes in temperatures and precipitation. The increase in winter minimum temperatures has contributed to an outbreak of mountain pine beetle that has devastated the lodgepole pine forests of the Central Interior. The cascading impacts of hundreds of thousands of hectares of dead lodgepole on fire regimes, hydrologic regimes and other ecosystem components and processes is yet to be determined. In the northwestern portion of the Central Interior, increased summer temperatures and precipitation have likely contributed to an outbreak of *Dothistroma* needle blight in young lodgepole pine. Douglas-fir beetles are taking advantage of trees already stressed by spruce budworm and increased summer drought in the southern portion of the region. Warmer temperatures and possible reductions in summer precipitation may result in a loss of closed forests and significant increases in open forest and grassland. This may be accompanied (or driven) by changes in fire regime with larger and higher severity fires resulting from increased temperatures and currently high fuel loadings. Decreased snowpacks and increased evaporative demand may impact water levels, salinity and algal growth in wetlands, lakes and ponds.

In the Southern Interior increased summer temperatures combined with reduced summer precipitation are expected to increase fire frequency and severity. Some systems (e.g. the Interior Cedar Hemlock Zone) have a high diversity of tree species that may increase ecosystem resiliency in those areas, but other systems are expected to see significant impact. Open forest and grassland communities are expected to expand in many valley bottoms, while alpine ecosystems will eventually be substantially reduced. Reduced snowpacks due to warmer winters, increased summer temperatures, combined with eventual loss of alpine glaciers will impact stream temperatures and low flows in many river systems in the Southern Interior. Increasing stream and lake temperatures will likely have significant impacts on cold water aquatic systems. The presence of invasive species, reservoirs, agricultural development, and human settlements in valley bottoms will likely limit the ability of many species to shift their distributions in response to changing habitat conditions, and affect the condition of newly forming plant communities.

For Coastal BC, although absolute temperature and precipitation changes may be less than some areas of BC, the relative increase in temperature particularly in winter, plus drier summers, and increases in the frequency and magnitude of extreme weather events will still likely have significant impacts. The drier parts of the southern coast may experience increased fire frequency and pest outbreaks (e.g., Douglas-fir and fir engraver beetles). Wetter parts of the coastal region are already experiencing dieback in yellow cedar, thought to be attributed to changes in freeze-thaw cycles. Drier summers may result in hemlock looper outbreaks. An increased incidence of large storms in Coastal BC will increase windthrow disturbance, the occurrence of landslides and potentially the frequency and magnitude of peak flow events. Warming winter temperatures may convert snowmelt-dominated watersheds to mixed/hybrid systems, and mixed/hybrid systems may become rain-dominated systems. All these factors have the potential to negatively impact aquatic habitat and water quality. Anadramous fish species, and ecosystem process linked to them will be impacted.

Traditionally forest management has striven to establish certainty in forest management ï initially through applying the principles of sustained yield and the ñnormalized forestò These have been slowly replaced by concepts of sustainable forest management, natural variability and maintenance of ecological integrity. With the advent of rapid climate change, and a growing understanding of the potential consequences for forest and range ecosystems and their linked socio-economic systems, there is need for further evolution in the paradigm of forest management.

The first step in formulating policies and designing actions to respond to climate change is to understand the scope of the problem in terms of the ecological systems and the related social systems. Vulnerability assessments are needed to examine the potential exposure of systems to climatic changes, the systemsô sensitivity to those changes, and the systemsôadaptive capacity to cope with the changes.

Due to the ongoing uncertainty around both the magnitude and rate of climate change, and the potential ecosystem responses to that change, forest management decision-making is rapidly becoming more complex. It is recommended that climate change adaptation be incorporated into all levels of decision-making through the application of a risk management framework. It is also important to recognize that adaptation strategies can only be successful within a limited window of future climate change ï therefore it is also crucial to be communicating the potential impacts of climate change and the benefits and limitations of adaptation to those assessing the costs and benefits of mitigation strategies to reduce GHG emissions.

Lastly there is a need for adaptation action. This will require significant effort to provide knowledge and decision-support tools to policy-makers and managers, to identify and eliminate barriers to implementation (institutional, financial and psychological), to develop a flexible and responsive adaptive management framework to govern implementation, and continuous monitoring to ensure that actions are responding to the most up-to-date information available.

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

Climate change is becoming a significant decision-driver globally. The Inter-governmental Panel on Climate Change (IPCC www.ipcc.ch) has recommended developing iterative Vulnerability Assessments to understand the scope of potential change, and to identify appropriate and timely responses. Step 1 in developing a Vulnerability Assessment is to identify potential impacts to ecological systems, with the understanding that ecological systems underpin all of human society. Without healthy ecological systems economies will fail. For agencies that deal with land use policies this first step can help to identify initial areas of policy that should be reviewed through the climate change lens.

In this document, observed and potential future impacts of climate change on ecological elements in BC are summarized (Section 2). This information is based on:

- a series of background documents prepared by ministry scientists for the FFEI Vulnerability Assessment of Forest and Range Ecosystems in BC project (available at: http://www.for.gov.bc.ca/hts/Future_Forests/),
- information from a technical workshop held in November 2008, and
- supporting evidence from the IPCC and other references.

Information is organized and presented first for specific ecological processes and components, and then it is synthesized into four broad regional summaries.

This impact analysis focuses on forest and range ecosystems. It is not intended to provide an exhaustive or comprehensive list of all the potential impacts of climate change on ecological systems ï rather, the intention is to identify some broad trends and key areas of concern.

This report limits its focus on climate change impacts. However, it is through alteration of our existing management regimes that adaptation strategies can be developed. Therefore it is also important to consider how our management practices and climate change may interact and exacerbate or off-set potential impacts.

Rapid Climate Change Is Here

Understanding potential impacts requires knowledge of the scope of climate change that has occurred to date, and what is expected in the future. In their most recent assessment, the IPCC states:

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level….,[and that] …..observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases* (IPCC 2007a, pp.30-31)*; ……*
>
> *most of the observed increase in global average temperatures since the mid-20th century is* ***very likely***[1] *due to the observed increase in anthropogenic GHG*[2] *concentrations* (IPCC 2007a, p. 39).

[1] The IPCC defines various terms of certainty, e.g., very likely is defined by the IPCC to be 90-99% probability (see IPCC 2007b).

[2] Greenhouse gas

In B.C., average warming trends already exceed the global average, with even higher rates of change in the northern reaches of the province (Rodenhuis et al. 2007). Precipitation trends are mixed, generally showing increases in annual precipitation, with drying trends in the summer in the south and summer increases in the north. Extreme weather events seem to be increasing. All these factors will influence ecological, and therefore social and economic values into the future. Potential climate futures are being modelled, demonstrating the broad implications of alternate global greenhouse gas (GHG) concentrations and human responses (e.g., Hamann and Wang (2006) for ecosystems in BC). Yet, we appear already to be beyond the ôlow impactô climate scenarios that suggest what may be possible if we act quickly (Canadell et al. 2007). The short- to mid-term timeframes for all scenarios are very similar to one another . Mid- to long-term rate of change will be more dependent on what actually happens to GHG emissions. As critical limit thresholds are crossed, potential futures start to diverge more significantly from one another. As a result of this moving baseline, and the lack of a specific understanding of how ecology will respond, this document focuses on the trends of impacts that may occur, with the assumption that the timeframe of when they will occur is unclear and will depend on the path that we follow globally. A more detailed climate change context is provided in Appendix 1.

A New Future for Decision-Makers?

The process of undertaking Vulnerability Assessments as outlined by the IPCC provides a framework for breaking a gargantuan task into manageable pieces, allowing policy-makers and stakeholders to become familiar with information and impacts as they are compiled. The approach and background for various other aspects of Integrated Vulnerability Assessments are outlined in Appendix 2. In addition, a summary of what is being assessed and whether ôchangeô will be significant or key is also outlined in Appendix 2.

The novelty, scope and rate of climate change alters the shape of how information can be used to make decisions. Traditionally, new information and ideas emerge and are slowly tested, accepted or rejected and perhaps then incorporated into management direction. However, the rapidly increasing rate of information about climate change and the grave concerns that each report raises, change how information must be considered. Daily, new information arises that puts yesterdayôs predictions of the scope of change out of date. And yet, policy-makers today must respond to speculation about events in the future. We find ourselves in the worrying predicament of having to make critical decisions that can dramatically alter the future state of our region, while not yet really seeing the scope of predicted impacts ï though the MPB epidemic should give us a glimmer of the future potential impacts. The science is clear that we have a very limited timeframe in which to act. The opportunity to influence the future ï from both an adaptation and mitigation perspective ï is short.

Uncertainty has always been a concern, and ôsomething to manageô yet uncertainty takes on a more important role under climate change. Since the implications of inaction are potentially so devastating, a risk management strategy that explicitly incorporates the consequences of a decision combined with its certainty is more relevant than ever.

Chapter 2 is the first step in a Vulnerability Assessment - providing a summary of potential impacts for BCôs forest and range ecosystems. Chapter 3 of this document provides a framework within which to investigate options for reducing future impacts, and to formulate the next steps in the on-going task of undertaking a comprehensive Vulnerability Assessment.

Finally, it must be noted that this process focuses primarily on adapting to climate change. Yet, the science is clear that without significant mitigation, the adaptation potential of both the biophysical systems and human systems will be quickly swamped. Mitigation of climate change should become a primary focus of decisions, and looking for synergies, (or contradictions) between adaptation and mitigation policies should be the second theme as policy-makers look forward to the future.

2.0 CLIMATE CHANGE IMPACTS

2.1 Introduction – Approach/Concepts

Climate change can impact forest and range ecosystems in a number of direct and indirect ways. Temperature-related impacts include changes to mean temperatures, changes to the magnitude and frequency of extreme high or low temperatures, and modifications to the seasonal distributions of temperatures. Examples of direct effects of temperature impacts could be killing frosts, expanded growing seasons or seasonal effects on phenology ï the timing mechanisms used by species to compensate for seasonal variation in the availability of food and climatic conditions. Changes in precipitation can be reflected as increased or decreased annual precipitation, or often of more significance, changes to growing-season precipitation and the frequency and magnitude of precipitation events. Examples of direct effect of precipitation changes include decreased snowpacks or increased frequency of extreme precipitation events.

Climate change impacts can also affect forest and range ecosystems via indirect means by affecting geomorphic processes, disturbance mechanisms or physical components of ecosystems (e.g., water, soils). Increased summer temperatures can lead to increased severity and frequency of fires, increased frequency of extreme storm events can lead to increased ecosystem disturbance by landslides, flooding and/or windthrow. Climate change can also indirectly affect ecosystems by facilitating outbreaks of pests or pathogens, or favouring the spread of invasive species.

The following sections provide summaries of potential impacts for ecosystem processes and disturbance mechanisms, and abiotic and biotic components of ecosystems. Under each section, there is a brief summary of the types of general impacts expected, followed by a summary of impacts that appear to be linked to climate change that has occurred already. Future potential impacts, with potential key thresholds or limits, where known, are then identified. Given the lack of specific BC studies, relevant information from elsewhere is also presented if it appears to define trends that may be mirrored in BC.

There is no one accepted climate change impact scenario for BC. The composite uncertainties in climate modeling (outlined in Appendix 1), compounded by a lack of detailed information on how ecosystems, ecosystem elements and process will respond to any given change in climatic variables, lead us to focus on impact trends on critical elements, processes and thresholds, rather than attempting to predict the timing of specific impacts associated with any particular scenario. In addition, coarse-scale regional summaries are provided for four regions of the province ï Southern Interior, Central Interior, Northern Interior and Coast (see Appendix 3 for description of regions).

Climate change impacts do not occur independent of other impacts on ecosystems. Although we are focused here on potential climate change impacts, other stressors remain relevant and may exacerbate climate change impacts (MEA 2005, Compass 2007, Warren et al. 2001). Previous studies have demonstrated that many ecosystems and species in BC are already under considerable stress due to the cumulative impacts of past human activities (Austin et al. 2008, Holt et al. 2003). Vulnerability evaluations by the IPCC have identified existing ecosystem stress as one of the key determinants of adaptive capacity for systems attempting to cope with climate change impacts (Yohe et al. 2007). In the regional summaries in particular, we will identify where specific synergies or cumulative effects may occur.

Compared to many jurisdictions, BC is well positioned to develop adaptation strategies to climate change. It is relatively wealthy, has a broad scientific community, mature forest and range inventory systems, sustainable forestry policies and extensive experience with stakeholder engagement processes. All of these elements are necessary to develop climate change adaptation policy (Aulisi et al. 2008).

The ecological impact summary is partially based on: a series of background papers written by BC government scientists as part of the FFEI program (available at http://www.for.gov.bc.ca/hts/Future_Forests/), a technical workshop held in November 2008, additional published literature, and professional opinion.

The IPCC (2007a) uses their two-tiered system of presenting how certain they are about potential impacts (likelihood and confidence). This level of analysis has not yet been applied in BC, but could be part of a more comprehensive integrated assessment for BC. This preliminary roll-up of information to date was not of sufficient scope to attempt such a level of scrutiny.

2.2 Impacts on Ecosystem Processes and Disturbance Mechanisms

General: Changes in temperature and precipitation regimes, as well as the magnitude and frequency of extreme weather events will have significant impacts on many geomorphic processes, disturbance mechanisms and internal ecosystem processes / functions that control the distribution and composition of all forest and range ecosystems (e.g., Dale et al. 2000).

Most terrestrial and aquatic ecosystems in BC have adapted to specific disturbance regimes that have operated within a limited range of variation over the past few thousand years (Bunnell 1995; Wong et al. 2003). The species and age class distributions of forests across BC generally reflect this, and both the biogeoclimatic classification (BEC) and Natural Disturbance Type (NDT) system are based on this assumption. Changes to disturbance regimes such as fire, windthrow and landsliding brought about by climate change will have profound effects on terrestrial forest and range ecosystems. Geomorphic and hydrologic processes also determine the quantity and frequency of sediment resulting from landslides and waterborne erosion and the magnitude and frequency of peak and low flows, all of which play major roles in determining the extent and quality of aquatic habitats.

These processes and mechanisms work at various spatial and temporal scales, driving biochemical and hydrological cycles at global and regional long-term scales, ecosystem distribution and successional patterns at landscape scales over years to centuries, and ecosystem structure and phenology of individual species at the finest scales and shortest time increments (FSP-BCFS 2008). Obvious drivers such as fire frequency and severity have seen a significant amount of attention to date, but many other more obscure processes have seen little or no detailed attention.

Impacts Observed to Date:

Changes in seasonal distribution of precipitation, increases in spring and summer temperatures, and an earlier snowmelt have already lengthened the average fire season, and increased large wildfire activity in western North America (Westerling et al. 2006), However, the Pacific Decadal Oscillation cycle also plays a significant role in controlling these conditions (Morgan et al 2008), making trend detection more difficult. Changing fire frequency is significant because the frequency and intensity of fire plays a key role in the distribution of ecosystems in BC, as well as directly and indirectly affecting seral stage distribution, nutrient cycling and hydrologic regimes.

Recent storm events on Vancouver Island that included high intensity precipitation, high winds and rain on snow have already demonstrated that extreme weather events can result in dramatic increases in landslides, debris flows and flooding (Guthrie et al. In press).

The mountain pine beetle outbreak is a significant example of a change in disturbance agents / landscape processes that has occurred to date (Taylor and Carroll 2004). A changing climate crossed ecological limits, and allowed the epidemic population explosion to occur and spread. In this case, climate change worked in concert with landscape condition ï since fire suppression activities had resulted in a landscape capable to supporting this massive population explosion. Similar patterns are now being observed in other outbreaks such as *Dothistroma* (Woods et al. 2005), although in that case the ecological limits that are being surpassed are different and involve the combination of increased temperatures and wetter conditions. Similarly, Douglas-fir beetle outbreaks in the southern and central interior have been linked to increased western spruce budworm activity and possible climate change-induced drought and windthrow events. Yellow cedar is in decline along much of the coast and birch is declining throughout its range. Both are thought to be at least partially linked to climate change. (MoF Forest Health Brief 2008).

Projected Future Impacts:

Increasing fire frequency and severity are expected province-wide, with regional variation of the significance of those changes (see regional summaries). In some areas, these changes are expected to be very large, and so have very significant outcomes: modeling for central-eastern Alberta suggest further increases in frequency (50%) and area burned (90%) with a doubling of CO_2 by 2050 (Krawchuck et al. 2009). Increases in the frequency and magnitude of extreme heat wave events may increase fire intensity and severity of fire impacts (Hawkes and Flannigan 2005). Key impacts will potentially result where changing disturbance regimes will result in a change in state of the primary ecosystem ï e.g., grassland to desert or forested ecosystem to grassland or scrubland. These changes may be irreversible, and the period of instability may result in extreme human hazard (e.g., Australian and California bush fires). Since disturbance processes largely define the nature of ecosystems on a landscape and on a site, the cascading impacts through all levels of biodiversity will be significant. Species and ecosystems will be affected through direct mortality, population dynamics and loss of habitat for specific species.

Geomorphic and hydrologic processes are closely intertwined, and directly and indirectly link to both precipitation and temperature regimes. Increasing temperatures in northern Canada are projected to have significant impacts on the character of geomorphic and hydrologic processes in permafrost landscapes (Couture and Pollard 2007). The ecological significance of melting in these systems is largely unknown at this time, but may add to the feedback loops as a result of increased carbon emissions from these ecosystems.

Future changes in temperature and precipitation patterns and increases in storm frequency and intensity are all predicted for various parts of BC (Sillman and Roeckner 2008, Tebaldi et al. 2006, Pike et al. 2008 a,b,c, see further information in Appendix 1). Key future impacts related to resulting increased landslides and increased wind disturbance include long-term loss of productive forestland, loss of infrastructure, potential human hazards, channel instability, reduced water quality, and degradation or loss of aquatic habitat.

Increased winter temperatures can result in decreased snowpacks, and when these are combined with increased summer temperatures and decreased summer precipitation they can result in prolonged droughts and lowered water tables. Aquatic and riparian ecosystems are most directly exposed to these impacts, and specific key habitats will be affected (see below). Terrestrial ecosystems will also be affected with predicted increases in plant water stress to range from 20% - 60% depending on climate scenario and region (Spittlehouse 2008). Cascading impacts can occur as vegetation responds directly to climate change, causing changes to water interception, evaporation and transpiration thus affecting water balance and streamflow. These effects are not trivial. For example, a 6-10% increase in transpiration is predicted for a Douglas-fir forest with a 2-4^{O}C increase in temperature (Spittlehouse 2008).These changes have significant implications for ecosystem productivity. Pike et al. (2008 a,b,c) provide additional detail on potential impacts of climate change to hydrologic processes in particular, and their downstream effects.

Much speculation exists as to what future outbreaks of forest pests and pathogens may occur. In some cases the change from endemic populations to epidemic outbreaks is contributed to by exceeding some climatic threshold ï for example a sequence of wetter than normal summers (Woods et al. 2005), a series of warmer than average winters (Taylor and Carroll 204), or changes to some other climatic variable. Changes in climate may provide opportunities for insect populations to expand their ranges, increase overwinter survival, increase their growth rates, or lengthen their growing season, and thereby increase opportunities for epidemic outbreaks. Increased summer drought, temperature variability and freeze-thaw events can also create conditions where stressed trees are more susceptible to pests (e.g., Douglas-fir beetle, birch die back). Changes in phenology of trees and pests can affect interactions between the two, sometimes increasing or decreasing susceptibility. One of the key factors in predicting increased impacts from pests and pathogens is that trees take many years to mature and they may take decades to extend their range, while pests and pathogens reproduce rapidly and are generally very mobile, easily adapting to new conditions (MoF Forest Health Summary 2008).

In general, disturbance and other processes will have some of the largest potential future impacts on ecological systems. Processes define ecosystems and typically determine the extent and distribution of different habitats across the landscape. Climate change impacts on any of these processes is likely to have significant impacts in the future. However, ‘unknown unknowns’ are likely to be very significant within this type of impacts. At this point we can only speculate based on past experience, but in this case the past is not likely a good indicator of a climate change future (Millar et al. 2007).

2.3 Effects on Ecosystems and Ecosystem Components

How ecosystems and various ecosystem components will respond to changes in climate depends on a number of factors. The first is their ***exposure*** to climate change. As indicated above, climate change will not be consistent across BC. Some parts of province will have greater and lesser changes in means of temperature and precipitation, as well as changes in climatic variability, and the occurrence of extreme climatic events. Others will have increased exposure to secondary levels of impacts such as sea level rise of changes in fire frequency.

Secondly ecosystems have differences in their ***sensitivity*** to the climatic changes to which they are exposed. Ecosystems whose distribution and productivity are primarily controlled by physical features such as soil texture or gravitational geomorphic processes, or even by climatic variables that are not significantly changing in that location, may be less impacted than those that are reflective of specific climatic variables that are undergoing significant change.

Thirdly response will depend on ***adaptive capacity*** - ecosystems’ ability to adjust to climate change (including climate variability and extremes), to contain potential impacts or to cope with consequences. Adaptive capacity in ecosystems can take various forms, from resistance to migration. In situ responses are essentially a measure of ecosystem resilience, the ability to reorganize following disturbance or to adapt to changing conditions while still maintaining similar controls on structure and process. Migration will be highly dependent on the rate of climate change, and the availability of suitable environments to migrate to.

One of the most important factors in ecosystem response to climate change is their present condition and context. Many forest and range ecosystems in BC have already been disturbed, fragmented, simplified, or are under stress, from urban and agricultural development, forest harvesting, forest practices or other human activities (Austin et al. 2008, Holt et al. 2003). Existing stress will play a significant role in limiting the ability of ecosystems to adapt to climate change (Yohe et al. 2007). Those ecosystems with intact diversity, connectivity and functions will be better equipped to respond to climate change than those that are already stressed or degraded (Noss 2001; Hansen et al. 2003; Pyke 2004; Wilson and Hebda 2008).

General:

With regard to ongoing affects at a global level, the IPCC Fourth Assessment Report states:

> *Based on growing evidence, there is **high confidence** that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snowfed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality.There is **very high confidence**, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is **high confidence** that there has been a trend in many regions towards earlier ‘greening’ of vegetation in the spring linked to longer thermal growing seasons due to recent warming. There is **high confidence**, based on substantial new*

evidence,that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. (IPCC 2007a, pp. 32-33)

With regard to future impacts at a global level, the Fourth IPCC report goes on to say:

> *The resilience of many ecosystems is **likely** to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. landuse change, pollution, fragmentation of natural systems, overexploitation of resources). Over the course of this century, net carbon uptake by terrestrial ecosystems is **likely** to peak before mid-century and then weaken or even reverse, thus amplifying climate change. Approximately 20 to 30% of plant and animal species assessed so far are **likely** to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C (**medium confidence**). For increases in global average temperature exceeding 1.5 to 2.5°C and in concomitant atmospheric CO_2 concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply. (IPCC 2007a, p.48)……Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems* (IPCC 2007a, p.52).

The assessment report also provides commentary on the risk of abrupt or irreversible changes that may have even more significant medium- to long-term impacts.

> *Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change…... If a large-scale abrupt climate change were to occur, its impact could be quite high. ……Current models project that such changes would occur over very long time scales (millennial) if a global temperature increase of 1.9 to 4.6°C (relative to pre-industrial) were to be sustained. Rapid sea level rise on century time scales cannot be excluded. Climate change is **likely** to lead to some irreversible impacts. There is **medium confidence** that approximately 20 to 30% of species assessed so far are likely to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. Based on current model simulations, it is **very likely** that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century.* (IPCC 2007a, p.53-54).

2.3.1 Abiotic Components

Hydrologic Features

Observed Impacts to Date

Within British Columbia, studies have confirmed that regional trends are consistent with the evidence a the global level. Rodenhuis et al. (2008) provide the following summary of important hydrologic trends over the past century:

- **Snowpack**: losses of April 1st snowpack of -25% on average at BC sites and as much as -50% at a few sites over the past 50 years. For shorter record lengths, however, the variability was large and not homogeneous across the Province. In addition, ENSO[3] influenced snowpack by

[3] ENSO is a tropical Pacific phenomenon that influences weather around the world and across Canada with periodicity of 2 to 7 years and events persisting for 6 to 18 months.

-12% to +21%. The geographical complexity of snowpack in BC prevents a simple interpretation of results.

- **Glacier Loss**: trends in glacier volume over the 1985-1999 period, demonstrate an annual rate of volume loss of 22.48 ± 5.53 km^3 per year from the glaciated areas of BC. These trends indicate that many glaciers are out of phase with the current climate (i.e. rapidly decreasing volume as the climate warms). Currently, the Western Canadian Cryospheric Network (WC2N) is working to project the response of glaciers in Western Canada to climate change.
- **Streamflow Changes**: changes in streamflow have occurred throughout BC, but depend on the hydro-climatic region and the streamflow regime. The timing of spring runoff has advanced (10 to 30 days) in runoff regimes dominated by snowmelt runoff. For watersheds at low elevations and southern latitudes that have lost their glacier influence, the annual mean streamflow decreased and the minimum daily average streamflow decreased. This result was consistent with the impacts of warmer temperatures in mixed snow/glacial runoff regimes.
- **Spring Break-up**: decreased duration of lake ice in the most recent records (0 to 42 days). The spring break-up of lake ice also occurred up to 10 days earlier, although one station in the north-eastern portion of the Province showed a later break-up by 2 days.

Projected Future Impacts

Continuing changes in precipitation and temperature regimes will have further direct impacts on hydrologic processes and hydrologic features such as lakes, rivers, wetlands and groundwater (Pike et al. 2008a, 2008b, 2008c). Increases in the magnitude and frequency of extreme storm events will likely be a major factor, particularly as they affect peak flow events. As discussed above, changes to geomorphic and hydrologic processes will have impacts on streamflow and water quality. A general summary of key impacts includes:

- altered timing and magnitude of streamflow due to:
    - increased magnitude and frequency of peak runoff events ï leading to flooding, channel instability and degradation of aquatic and riparian habitats,
    - increased duration and frequency of low flow events ï leading to degradation or loss of aquatic habitats and reduced water availability for human uses,
    - changes in snow accumulation, snowmelt and timing of peak flows ï leading to potential flooding, channel instability and degradation of aquatic and riparian habitats,
    - changes in glacier dominated systems ï leading to initial modest increases in summer flows, followed by substantial reductions in summer flows and reduced water availability (Hall et al. 2003, Stahl et al. 2008);
- increased atmospheric evaporative demand ï resulting in lower water tables and drought, reduced stream flows and demand for irrigation diversion waters;
- increased stream and lake temperatures ï resulting in altered aquatic habitats (discussed further below);
- altered sediment regimes due to increased landslides, windthrow and/or channel instability ï resulting in degraded aquatic habitat and reduced water quality.

Many of these changes to the hydrologic system are complex and interactive. For example, changes in temperature affect snow accumulation and snowmelt timing, which in turn have potential impacts on peak flow, low flows and groundwater storage. However, the impacts of these changes will not be evenly distributed, varying between areas of differing exposure to climate change (see Appendix 1 for further information on exposure) and differing hydrologic regimes. As summarized by Pike et al. (2008c, p.4):

> *In British Columbia, there are four types of hydrologic regimes: 1) rain-dominated (coastal), 2) snowmelt-dominated (interior), 3) mixed/hybrid (coastal transition), and 4) glacier-augmented*

(mountainous areas). The relative impact of climate change will vary by hydrologic regime depending on the regime's sensitivity to regional temperature and precipitation changes.

The response of rain-dominated regimes (winter peak flows, summer low flows) will likely follow predicted changes in precipitation. For example, an increased frequency and magnitude of storm events will result in an increased frequency and magnitude of storm-driven peak flows in the winter. Drier summers will raise concerns about the increased number and magnitude of low-flow days (i.e., less water for a longer period of time).

In snowmelt-dominated systems (spring peak flows, late summer– winter low flows) there will be a shorter snow accumulation season and likely an earlier start to the spring freshet, which may lengthen the period of late summer and early autumn low flows.

In mixed/hybrid regimes there can be significant streamflow (peaks) in both the winter as a result of rain and in the spring as a result of snowmelt from higher elevations. In these regimes, if snowpacks no longer form or are very shallow, typical large midwinter snowfall events will change to large rain events, thereby increasing the frequency of winter peak flows. Subsequently, spring peak flows will be reduced and will occur earlier due to less precipitation being stored as snow during the winter, and winter low flows will be reduced (i.e., more water) if precipitation falls as rain instead of snow.

In glacier-augmented systems, peak flows would likely decrease and occur earlier in the year, similar to snowmelt-dominated regimes. In the long term, the reduction or elimination of the glacial meltwater component in the summer/early fall would increase the frequency and duration of low-flow days in these systems.

Overall, it could be expected that hybrid/mixed regimes might transition to rain-dominated regimes through the weakening or elimination of the snowmelt component. Similarly, snowmelt-dominated watersheds might exhibit characteristics of hybrid regimes, and glacier-augmented systems might shift to more of a snowmelt-dominated pattern with respect to the timing and magnitude of annual peak flows and low flows.

Many of the predicted direct impacts of climate change on hydrologic systems will be further amplified by indirect impacts. For example, reductions in forest cover caused by increased magnitude and frequency of fires or pest infestations can also increase peak flows and further decrease water quality by increasing the occurrence of landslides and waterborne erosion.

Landforms, Parent Material and Soils

Observed Impacts to Date

Recent intensive storm events have had substantial impacts on landslide activity and flooding (Guthrie et al. in press); however, the impacts are limited to site-specific locations. Glaciers have been receding in BC at a significant rate (Stahl and Moore. 2006). The slow rate of change in soil properties and the lack of monitoring have meant that there is no information on how they have been affected to date.

Projected Future Impacts

As discussed above changes to geomorphic and hydrologic processes will have impacts on landforms in some locations. Increased magnitude and frequency of extreme precipitation events, rain-on-snow events and/or accelerated rates of snowmelt may all increase the rate of landslides. As well as affecting upland landforms, these events can alter fluvial landforms where materials are deposited on floodplains or fans, or where the materials deposited in streams contribute to channel instability. These will have significant impacts on aquatic and riparian habitats, as well as aquatic species. In northern BC and other alpine areas where permafrost presently exists, warming temperatures will have dramatic impacts on landforms.

Sloping areas and streambank areas may experience increased instability, and gentle terrain may undergo subsidence. Loss of glaciers will expose new landforms to vegetation establishment, both on morainal materials themselves and stabilized glaciofluvial materials downstream of major glaciers.

The future impacts of climate change on soils are complex, being both direct and indirect. Increases in temperature and changes in precipitation will affect soil development through changes to chemical, physical and biological processes within soils. Biological processes and properties, in particular those related to carbon cycling and storage, will be affected by changes to temperature and precipitation regimes. Increases in temperature and precipitation will likely speed decomposition in many soils, and potentially lead to a reduction in carbon storage, especially in northern soils where temperature increases will be greatest (this may provide a positive feedback to climate change). Soils in the drier portions of the central and southern interior may undergo substantial changes in carbon storage and soil processes due to increased temperatures and decreased precipitation during the growing season. Where these changes are compounded by grasslands shifting toward annual grasses and/or weed-dominated plant communities, and forested areas shifting to grasslands, rates of decomposition, nutrient cycling, weathering, organic matter inputs and cycling, nitrogen fixation, and other physical and biological properties of soils will also change. In some cases a lengthened growing season, caused by increased temperatures in the spring and fall, may offset some of the changes due to drier and hotter summers. However, changes to soils will vary by ecosystem and will take decades, if not centuries, to be fully manifested. The composition of soil biotic communities, the biological processes mediated by these organisms, and the complex interactions among soil organisms, and between soil organisms and their environment, will also be affected, but the magnitude and direction of these changes are largely unknown.

2.3.2 Biotic Components

General

Species ranges and population dynamics are influenced by a wide range of factors, including finding food sources, mates, avoiding predators, interacting with other species, and climate factors such as temperature ranges and precipitation regimes. Changing climate therefore will influence species and their habitats directly and indirectly in a multitude of ways. Even minor changes, such as changes in the frequency or timing of freeze-thaw cycles can have significant impacts for some species (e.g., yellow cedar, Hennon et al. 2005, Henry 2008), In addition, many indirect effects will occur as patterns of habitat change as a result of cascading effects of changes in disturbance processes and hydrologic regimes. However, there is no reason to expect that as climate envelopes shift, species will simply shift with those climate envelopes. This is because of the wide range of other factors affecting life histories (Pimm 2007), and the limited rate of dispersal for most species.

Changing climates may affect species directly by shifting the suitable climate envelope they now occupy through space. Formerly inhabitable areas may become habitable as a result of increasing temperatures or altering of moisture regimes. However, for many species, their envelopes may not just shift in location, but may in fact, no longer exist. Extreme weather events can directly cause mortality of individuals (e.g., killing frosts). Extreme events are expected to increase in frequency and / or severity so have the potential for significant impacts to vulnerable species in future.

A few species are relatively easy to link to their habitats and others are easily linked to another species (e.g., lynx and snowshoe hare). However, for most species there is little known information on tolerances to climate shifts or the complexities of speciesôinteractions with one another (see also Appendix 2, Figure A6). There is generally even less understanding of evolutionary processes. The lack of basic knowledge and the complexities of interactions are such that development of solid accurate predictions for even a small number of key species will be extremely difficult (Araujo and Rahbek 2006).

The extent to which species are able to move will relate to inherent mobility, population dynamics, natural barriers (e.g., mountain ranges) and human-made barriers (roads / fragmentation of habitat). Understanding how species migration may play out in BC will be complex.

The predicted shifts in climate envelopes for BC are expected to alter the distribution of ëecosystemsô across the landscape. Modeling for shifts in biogeoclimatic zonal climate envelopes has been presented for BC (Hamann and Wang 2006), but impacts will affect ecosystems at all scales. More detailed mapping of potential shifts of biogeoclimatic zonal climate envelopes has been completed for the Kamloops area (Jones and Brown 2008). Both studies indicate that some of the predicted climate envelopes do not have existing correlates in BC. Therefore it is likely that ñnovelò ecosystems will develop at the biogeoclimatic unit level, and given the complexity of landforms in BC, the likelihood of novel ecosystems at the finer levels of classification is even greater.

Terrestrial Species and Habitats

Impacts Observed to Date:

An analysis of a wide-ranging assortment of almost 1600 species (based on available global trends) showed that 59% demonstrated changes in range or phenology over the past 20 ï 140 years (Parmesan and Yohe 2003). Furthermore, the trends were consistent with those expected based on climate change over that same period. Similarly, a meta-analysis of species changes observed over the last 100 years showed a consistent temperature-related shift or ëfingerprintô for 80% of the investigated species (Root et al. 2003). This demonstrates that globally, a wide-ranging set of species is already responding to the relatively low level of climate change that has occurred to date.

In BC, a number of species level changes have been observed. Evidence that species ranges and populations are already shifting includes:

- Twenty five bird species were found recently in BC that were not present in 1947 (T. Stevens, pers. comm.). In addition, preliminary analysis suggests birds are returning significantly earlier to BC. This may signal the start of significant decoupling migration timing and emergence of local food sources which may have many rippling impacts through forested ecosystems of BC (Bunnell and Squires 2005).
- Species are responding to changes in previous limits to population growth due to direct climate shifts (e.g., 13 million ha of BC affected by mountain pine beetle epidemic by 2007), while others show dieback effects due increased stress (e.g. western redcedar and yellow cedar ï Wilson and Hebda 2008; Hennon et al. 2005). Many other less obvious species are presumably undergoing similar shifts with currently unknown consequences. A large meta-analysis of tree mortality for the pacific coastline of North America suggests a significant increase in tree mortality within the last 30 years (van Mantgem et al. 2009). Campbell et al. (2008) note: despite having wide geographic ranges, most North American conifer populations are highly differentiated and locally adapted.
- There is evidence of disruption of pollination processes by a mixed set of factors that are thought to include climate change (CSPNA 2007, Klein et al. 2007). Although direct links to climate change are not yet known in BC, the potential for impacts are high. Many pollinators are sensitive to temperature in the spring, while their pollen plants may be differently sensitive.
- Phenological changes have already occurred with implications for many species that have co-evolved with a few or even a single other species to maintain key life-history stages. Because species will respond to climate change differently (some take cues from temperature, others from daylength, and others from cues many miles away on a migration route) decoupling of these life-history cycles may occur. Decoupling has been identified in a wide variety of examples to date, including: Great Basin American Pikas that emerged from hibernation too early resulted in extirpation of about one third of the subpopulations (Beever et al. 2003); decoupling of Cassinôs auklet breeding timing and food supplies on the BC coast resulted in significant reproductive failure (Bertram 2001); foraging difficulties occurred for yellow-bellied marmots in the Rocky Mountains that emerged early before foraging plants had yet bloomed, likely due to warmer air temperature (Inouye et al. 2000).

Projected Future Impacts: Species

A study of terrestrial species has suggested that between 15 ï 37% of species may already be committed to extinction by 2050 as a result of existing change (Thomas et al. 2004). The range reflects the uncertainty as to the speed and scope of climate change in the upcoming 40 years.

It is assumed, based on observed trends to date, that we can expect to see a continued increase in the number and types of species whose ranges shift across the BC landscape. Species currently distributed at the northern edges of their ranges will likely increase in number and range, while those at the southern edges may disappear completely. We can expect such shifts to become key impacts when ecological limits are crossed, allowing either rapid increases or decreases in population growth, or when the species affected are keystone, foundation or strongly interacting species. An example would be loss of predators resulting in significant population growth for prey species, with extensive cascading impacts for vegetation, habitat characteristics and multiple other species (e.g., Ripple and Beschta 2003).

In addition, the potential magnitude of some impacts will make them significant. For example, the magnitude of the MPB epidemic and its consequences is dramatic, yet it has been noted that this magnitude of outbreak occurred while ecosystems were considered ôhealthyö or ôresilientö, and that future outbreaks may occur within simplified and possibly less resilient systems. Outbreaks of a similar or even more dramatic nature can be expected in the future across ecosystems.

Decoupling of life history events (flowering, pollination, seed production) across species is expected to continue to occur at increasing rates as individual species respond to future climate change differently. Any of these events can be significant at the species level ï causing extinctions, and at a broader scale when ecosystem services or key species are affected (e.g., pollination events). Initial evidence suggests many species are unable to respond to changes in the timing of food supplies appropriately (Visser and Both 2005). The potential cascading impacts and ecosystem simplification are likely to be significant.

Range-restricted species (e.g., those with nowhere to move to such as ones limited to alpine areas, or at the southern most limits of their ranges) may become extirpated or extinct. Similarly, species associated with areas where the ecosystem is likely to shift from one state to another are also likely to be heavily impacted (e.g., open forest to grassland systems; Parmesan 2006). As changes to disturbance patterns change, these impacts will increase in magnitude and scope.

Increased frequency and severity of extreme weather events may result in additional mortality and population crashes that can lead to instabilities (e.g., population release and crash in predator-prey systems).

Any of these types of impacts can be considered potentially ôkeyö the number of potentially cascading or synergistic impacts occurring between impacted habitats and species are innumerable and impossible to foresee.

Projected Future Impacts: Terrestrial Habitats

Modeling estimates have suggested how BCÕs broad climate envelopes may shift, and how future biogeoclimatic units may shift in response (Hamann and Wang 2006, Jones and Brown 2008). Based on climate envelope shifts, most biogeoclimatic zones are expected to undergo changes of large orders of magnitude (see Table 1 and Figure 1), with some potentially expanding while others collapse. Of course, it is not expected that the ecosystems as we know them will shift along with the climate envelopes, merely that the climatic variables in the new areas are similar to where that biogeoclimatic unit existed in the past.

Table 1. Projected changes in the distribution of biogeoclimatic zone climate envelopes according to ensemble model CCGA1gax for the normal periods 2011-2040 (2025), 2041-2070 (2055), and 2071-2100 (2085), as modelled by Hamann and Wang (2006, p.2782).

Zone*	Elevation Shift (m)			North Shift (km)			Area Change (%)		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
AT	+168	+303	+542	-5	-67	-210	-60	-85	-97
BG	+104	+179	+243	14	16	9	159	418	773
BWBS	+37	+56	+199	18	53	78	4	-11	-44
CDF	0	+4	+7	23	87	156	62	176	336
CWH	+134	+224	+317	30	44	56	27	40	50
ESSF	+86	+143	+225	154	224	287	6	3	-27
ICH	+113	+194	+307	72	94	105	112	154	207
IDF	+40	-42	+55	85	264	349	38	160	149
MH	+263	+418	+597	35	69	109	-24	-52	-79
MS	-28	-22	+85	149	302	446	-19	-40	-68
PP	+175	+186	+218	10	278	614	12	53	452
SBPS	+143	+282	+471	-15	-13	-11	-49	-82	-98
SBS	+44	+191	+384	40	198	126	-13	-69	-85
SWB	+179	+410	+516	63	53	38	-69	-93	-99

*AT ï Alpine Tundra, BG ï Bunchgrass, BWBS ï Boreal White and Black Spruce, CDF ï Coastal Douglas-Fir, CWH ï Coastal Western Hemlock, ESSF ï Engelmann Spruce ï Subalpine Fir, ICH ï Interior Cedar ï Hemlock, IDF ï Interior Douglas-Fir, MH ï Mountain Hemlock, MS ï Montane Spruce, PP ï Ponderosa Pine, SBPS ï Sub-Boreal Pine ï Spruce, SBS ï Sub-Boreal Spruce, SWB ï Spruce ï Willow ï Birch

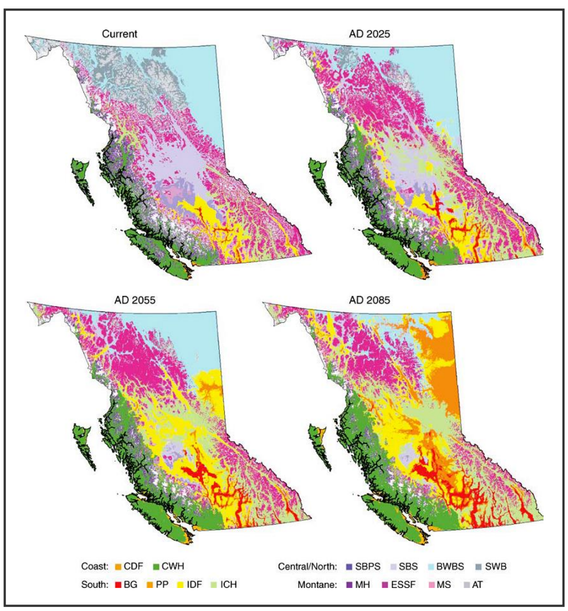


Figure 1. Shift of the climatic envelopes of biogeoclimatic zones (see Table 1 for zone names) based on the ensemble simulation CGCM1gax for the normal periods 2011–2040 (2025), 2041–2070 (2055), and 2071–2100 (2085), as modelled by Hamann and Wang (2006, p.2781).

Table 1 and Figure 1 outline potential BEC unit climate envelope shifts resulting from a "middle-of-the-road" climate change scenario similar to the A1B scenario (see Appendix 1 for information on scenarios). Predictions of BEC unit climatic envelope shifts for a scenario similar to the A2 scenario for the Kamloops TSA showed far greater potential changes (Jones and Brown 2008). Some of the climate envelopes predicted for the Kamloops area are similar to ones that now exist in Central Idaho.

Some key implications of the shifts outlined in the table are:

- shift of grasslands to desert conditions;
- shift of open forests to grasslands;
- shift of significant closed forest areas to open forests;
- shift of alpine areas to closed forest (assuming sufficient soils exist for tree growth);
- loss of habitats such as vernal / ephemeral wetlands that are maintained by run-off or rainfall waters and don't have a permanent water source; and,
- potential for massive disruptions as ecosystems adjust to new disturbance regimes over the coming decades (re-alignments of ecosystem components, structure and function due to exposure to new disturbance factors and patterns).

The overall impacts associated with such shifts are extremely difficult to assess. However, habitats in adjacent systems that are more similar to one another are likely to adapt more easily than those with largely dissimilar species compositions (see Campbell et al. 2008 for a summary of floristic similarities between zones).

Changes in habitat availability and distribution will affect population dynamics, and the functioning of larger metapopulations. Loss of high quality habitat (or general lowering of habitat quality across the board) may result in a higher chance of local extirpation, or extinction due to loss of source populations or higher distribution of sink populations. Sudden unexpected population crashes can result.

Biotic interactions can result from changes in the distribution of species typically not co-existing. Examples to date include diseases impacting new populations (e.g., extinction of honeycreepers in Hawaii, West Nile affecting crows and jays). Similar examples could easily occur in BC with incoming strains of avian flu, West Nile virus or diseases for other species. Invasive species of all kinds are expected to increase as habitats simplify or become disturbed, with significant potential for loss of productivity, simplification of flora, and loss of native food supplies.

Increased windthrow or tree mortality due to other factors may temporarily increase habitats related to snags and coarse woody debris, but increased fire frequency and/or intensity may more than offset those impacts in many ecosystems.

Specific habitats may be directly or indirectly affected by climate change – direct loss of rare habitat types such as vernal / ephemeral wetlands could occur as precipitation and evaporation levels change. Riparian habitats could be affected by reduced moisture levels and changing flood events. Impacts to critical habitats of this type can have significant cascading impacts as they provide habitat for a large number of rare and common species.

Any of these types of impacts can be considered potential 'key' impacts, especially those that result in loss of a key habitat for keystone, foundation or strong-interacting species and those that cause an ecosystem to flip from one state to another – this is an unstable process and provides a period of transition that may result in significant loss of services or cause extreme human hazard.

Aquatic Species and Habitats

General: In general, the types of impacts on terrestrial systems are equally applicable to aquatic systems. However, aquatic species are confined to aquatic environments and so are much more limited in their potential to shift their range in relation to climate change.

Observed Impacts

Significant shifts in streamflow have been observed in BC, and there are indications that landslides and other factors affecting water quality may also be increasing in frequency (see Sections 2.2 and 2.3.1 above). Some studies have shown increasing stream temperatures (Nelitz et al. 2007a). However there are as of yet no definitive studies linking these changes directly to aquatic species and habitats. Some studies are ongoing where long-term records exist, but it has proven difficult to distinguish between the effects of other watershed disturbances and climate change-related effects (P.J. Tschaplinski pers. com.). In addition much of the work on aquatic species in BC has been linked to anadromous species, where many of the impacts of climate occur in the marine portions of their life cycle (Nelitz et al. 2007a).

Projected Impacts

Increased lake and stream temperatures have significant implications for many fish species, affecting aspects such as ïfrequencies of disease, increased energy expenditures, altered growth, thermal barriers to both adult and juvenile migration, delayed spawning, reduced spawner survival, altered egg and juvenile development, changes in biological productivity and other rearing conditions, and altered species distributionò(Pike et al. 2008c, pp3-4).

Changes in lake and stream temperatures will alter aquatic habitats significantly, affecting biological productivity, species distributions and other aspects of various aquatic speciesôlife cycles. Specific loss of species may occur where species are close to thermal tolerances. Under these conditions, even small changes in temperature may cause local extirpation of individual species, or displacement by more tolerant species. This phenomenon will likely result in loss of species in some areas (Nelitz et al. 2007b). Effects of temperature will be exacerbated where they intersect with decreased low flows. Preston (2006), in a risk-based analysis of the effects of climate change on cold-water fish habitat across the US, predicts the potential for significant losses in cold-water aquatic habitat for the Rocky Mountains (median [and 95% confidence limits], 20-21% [12-30%] at 2025, 32-36% [20-58%] at 2050, and 48-51% [20-100%] at 2100, and for west coast salmon species (median 25-35% at 2100, up to 65% loss at 95% confidence levels). Other species further from key thresholds may have increased rates and sizes of growth, but with changing phenologies. For abundant fish species this has the potential to result in significant cascading impacts to other species reliant on synchronies with fish abundance (e.g., grizzly bears, eagles).

As indicated above in the sections on abiotic components and processes, many direct and indirect impacts will affect hydrologic regimes. Any changes to hydrologic regimes will likely lead to further impacts on aquatic species and habitats. For example, reductions in water quality and sedimentation resulting from increased landslides and erosion will reduce habitat quality, increased peakflows and potential channel instability may destroy or degrade some habitats, and decreased low flows that result in decreased dilution of waste discharges may make some habitats unsuitable. In drier parts of the province, reductions of summer precipitation and glacial meltwater inflows, and increases in evaporation rates may completely change the chemical and biological processes in lakes and wetlands, leading to possible eutrophication, algal blooms, fisheries collapse and/or increased salinity (Schindler and Donahue 2006, Michels et al. 2007). These effects will be amplified in systems where where agricultural, pollution and water diversions for human use are already creating stress on aquatic systems.

2.4 Regional Summaries

In this section, potential climate change impacts are rolled up into regional summaries for four broad areas of the province ï Southern Interior, Coast, Northern Interior and Central Interior (see Appendix 3 for general locations). These four regional summaries are based on existing information on predicted impacts, and highlight regional variation in the type and magnitude of climate impacts, and known or assumed adaptations of key species.

As outlined in the introduction and Appendix 1, climate futures are varied and uncertain yet will dramatically influence the rate and extent of future impacts. These summaries represent one of any number of possible future ôscenariosöï based on a multitude of uncertainties. The extent of climate change itself and how it will affect temperature and precipitation throughout space and time, and other factors that will affect ecosystems (such as CO_2 levels) is uncertain. The broad biogeoclimatic shifts used in these summaries are interpreted from Hamann and Wang (2006) ï which are based on a ômiddle of the roadö scenario similar to the A1B shown in (Figure A1 in Appendix 1), however the timeframes within which these changes are expected could vary widely depending on the actual rate of climate change. These predicted ôBECö changes are intended to ground some of the potential impacts, but do not imply that the zones will actually shift in some known way, just that the climate will shift, and the new locations will have a climate similar to what exists where those BEC units exist today. We have a poor understanding of how the components of ecosystems will shift, and our ability to predict potential interactions between different rates and types of shift is even weaker.

These summaries are based on a number of key references from different fields - Hamann and Wang (2006); Campbell et al. (2008); Guthrie et al. (In press); Pike et al. (2008a,b,c); Nelitz et al. (2007a).; Nitschke and Innes (2008) (for Southern Interior); Hawkes and Flannnigan (2005); Jones and Brown (2008); Nitschke (2008) (for Central Interior); Holt (2001).

Southern Interior:

The Southern Interior of the province is dominated by a series of north/ south valleys, separated by significant mountain ranges. The area is currently characterized by a wide range of habitat types, a high diversity of species, three of four biogeoclimatic zones of provincial conservation concern (IDF, PP and BG zones ï Austin et al. 2008), plus the highest densities of species at risk in the province. From a provincial perspective, existing impacts to functional biodiversity are relatively high and include the dispersed human population density, agricultural and rural development at low and mid elevations, some large valley bottoms flooded by reservoirs, and forestry development throughout.

Biogeoclimatic zone climatic envelope predictions suggest there will be significant ecosystem state shifts across much of this region. The main driver for change will be natural disturbance processes: fire season is expected to increase in length, particularly early in the spring, and warmer drier temperatures will combine to result in potentially larger and more severe fires particularly in high summer. Synergies with the effects of fire suppression to date and unnaturally high fuel loads in many low elevation forest types are relevant even without climate change, but in concert with climate change are likely to result in significant increases in fire frequency and severity. The direct effects of fire itself are many ï accelerated nutrient cycling, nutrient losses, direct mortality of trees and many other species, and ultimately changing soil characteristics.

Based on climate envelope shifts, currently forested low elevation zones may become dominated by grassland ecosystems, as something similar to the BG zone is predicted to increase by 700+% by 2085. This shift of disturbance types will have significant cascading impacts.

Nitschke and Innes (2008) outline a complex series of main and feedback effects for a geographic area in this zone including primary effects (increase in area burned and frequency of fire, species thresholds exceeded), secondary effects (reduction in disturbance refugia, loss of regeneration for some current species, and influx of new species) and tertiary effects (contraction and expansion of ranges, change in ecosystem composition, decrease in habitat for some fauna). They suggest the PP zone may become more similar to a BG zone, the IDF zone may become like the PP zone, and the ICH may become an integration of ICH and IDF – note though they do not expect all species and functions to move into these new "zones" as individual species move or adapt at different rates and scales.

In their pilot, more than 70% of the landscape had more than one tree species at risk from the climatic changes, with 5 species classified as at extreme risk (>90% range contraction), and 5 species at high risk (30-70% range contraction). When tree species become maladapted to their present locations (e.g., under drought stress), they can become less resistant to pathogens and insect attacks. For example, significant parts of the landscape become climatically suitable for western white pine and grand fir, but pests and pathogens are already creating serious problems for those species (blister rust / mountain pine beetle and fir engraver beetle on the coast respectively).

The landscape modeling estimates that 70% of animal species known to be present become classified as at medium to high risk as a result of habitat change, with species associated with older forest habitats most at risk as fire refugia are lost due to increased fire frequencies across a large portion of the landscape. Nitschke and Innes (2008) do not go further and identify the potential implications associated with reduced populations of this percent of the fauna, but significant impacts can be expected. This is particularly the case when impacted species are keystone (e.g. some woodpeckers), foundation species (e.g. tree species), or strongly-interacting species (e.g. predators) which could cause yet further repercussions throughout the ecosystem. Overall – the real implications to broader ecosystem resilience of this scale of rapid change are largely unknown but are likely to result in significantly reduced resilience.

Although warming temperatures may result in potentially increased productivity, reduced growing season moisture availability may decrease this gain (Spittelhouse 2008). Invasive species may also decrease productivity, particularly in grassland ecosystems. Invasive species are expected to increase in number and density when fire events expose increasingly large areas of ground, particularly where adapted native species may not yet have arrived. Many grasslands are already in poor condition in these zones (Forest Practices Board 2007), and continued invasion by non-native species is expected.

This area has the highest density of listed species in the province, plus some of the biogeoclimatic zones of most concern provincially (BG, PP, IDF). Some listed species at the northern edge of their zones may theoretically get an increase in potentially available range, and the north/ south directional trend of the major valleys may aid movement of individual species. However, extensive reservoirs and urban, rural and agricultural development particularly at low elevations will likely negatively influence the ability of species to move across this landscape and colonize potentially newly available habitats. However, in the ICH the relatively high tree species diversity will increase adaptive capacity in those areas.

Aquatic habitats are already at high risk in this zone, with extensive loss of wetlands, and high demand on water resources for agricultural and urban uses in major valleys. Decreased availability of moisture will likely exacerbate these effects, with vernal wetlands being particularly at risk from direct drying. These systems provide habitat to a relatively large number of listed species, which would be directly affected by additional loss of this already rare habitat type. Riparian ecosystems, which currently support a high density of species are also likely to be both directly and indirectly affected by changes in flow regime, and increased flooding and channel disturbances associated with increased frequency of storm events.

Direct temperature impacts are also expected for many aquatic systems in the southern interior, with the loss of up to 50% or more of cold-water fish species habitat (Preston 2006), implying a large impact for aquatic biodiversity and sport and commercial fisheries (e.g., salmon, bull trout, rainbow trout). Reduced snowpacks, and over the medium- and long-term loss of glaciers, will further reduce summer low flows in many river systems throughout the region. Many aquatic species could be affected by a combination of increased temperatures and reduced flows at some times of year (Nelitz et al. 2007a). There will be increased conflicts over water allocation – with increasing demands by fisheries, agriculture, domestic users, recreation users and hydro power producers.

Other effects include more rapid snowmelt and higher magnitude and more frequent large storm events which will increase landslide frequency and sediment delivery to streams. These effects will have further impacts on aquatic habitat, and also have significant impacts on roads, domestic and irrigation water systems and human settlements on fans and floodplains. Increased storms may also result in increased windthrow events, providing conditions for pest outbreaks (e.g., spruce beetle).

Overall ï very significant impacts of climate change are expected on ecological systems in this region due primarily to the predicted shift in state of existing ecosystems as disturbance and hydrologic processes change significantly. This combined with the existing high pressure placed on ecosystems and species from development may substantially reduce the potential for adaptation in this region.

Coastal Region

For this purpose, the coast of BC can be thought of in two broad regions ï the southern section of the coast, particularly in the rainshadow of Vancouver Island where climate is already warm and relatively dry, and the more exposed coastal systems with high precipitation levels and somewhat cooler temperatures (though they remain moderated to some degree by proximity to the ocean). The southern part of this system is densely populated with urban, rural and agricultural zones highly impacting and fragmenting remaining ecosystems. At higher elevations, and further north on the coast, forestry is the primary development, with varying histories of development depending on location. Physically, the coast is intersected by natural barriers to migration inland (the coast mountains) and south to north (by deep fjords and valleys).

Southern Coastal Dry Region: In the southern part of the Coastal region, dry ecosystems are expected to become warmer and drier still. The continued die-back of drought intolerant species (e.g., western redcedar) is expected to continue in this region, and the coastal Douglas-fir ecosystem is expected to expand its range northwards along the coast and upslope (300+% increase by 2085 modeled). Low and very low floristic similarity between CDF and adjacent zones suggests a high degree of novelty developing in the ónew CDFô Decreased moisture and increased temperature will result in higher fire frequency and perhaps more severe fires. As with the interior this may be exacerbated by already-high fuel loadings from fire suppression. Increased fire will have cascading impacts throughout the system ï existing very small areas of remaining mature and old growth forests (loss due to harvest and development) may be further reduced thus impacting the large number of at-risk species that exist in these forest refugia.

At higher elevations, impacts may be lower, as there is a potential for increased productivity in the mid elevation forests. Alpine habitats could become lost relatively quickly, as temperatures rise. Impacted species include high profile species such as the Vancouver Island marmot.

High value, high biodiversity habitats such as Garry oak and wetlands in this region are at high risk:ï based on climate, Garry oak ecosystems could be expected to expand their range, however there is an expected increase in invasive species at the same time, and much of the expansion is projected into areas with existing urban and rural development. Wetlands and functional riparian systems are already under high threat (combined habitat loss and invasive species) and this is exacerbated by the predicted climate changes. Cascading impacts include loss and extirpation of species from this zone and reduced ecosystem stability.

Flooding and channel changes associated with increased frequency of high severity storms may increase threats to aquatic habitats already under stress from urban and agricultural developments. Increased windthrow associated with these storms may create conditions for epidemic increases in some pest species. For example, Douglas-fir beetle outbreaks may increase as a result of drought conditions, and/ or as a result of increased frequency of wind-damaged trees. Fir engraver beetle is also killing Grand Fir in drier regions of the coast already; this relatively localized beetle in BC is a significant mortality agent in forests further south in the US, and can be expected to increase in BC.

Exposed Coast Region: In the wetter regions of the coast, effects on the general forested ecosystems are not so dramatic as in other regions. Temperature changes are somewhat moderated by proximity to the ocean, though precipitation trends are harder to outline. The wet coastal forests are not expected to undergo significant shifts in terms of disturbance dynamics, though in more southerly regions of the midcoast an increase in fire frequency is likely. The CWH climatic envelope is expected to increase in distribution moving to higher elevations, significantly reducing the distribution of the MH zone envelope, and further inland into some ICH and ESSF transition areas. There is moderate to low floristic similarity with some of these zones (38% with MH, ESSF 17%, ICH 41%), and it is unclear how smoothly these shifts will occur. The plasticity of some key species ï such as western redcedar is unknown, but it is a species of concern due to low genetic variability and high inbreeding. Yellow cedar dieback may continue as reductions in snowpack continue. Large-scale wind disturbance may increase in frequency, leading to lost forest structure and possible insect outbreaks.

Potential aquatic impacts however are thought to be significant in this zone. Increased marine temperatures are already believed to be having impacts on that portion of the salmon life cycle, and increased stresses will continue to grow on the freshwater portion as temperatures increase. Although it is hard to parcel out the impacts of different causes, increased stream temperatures from harvesting combined with climate change is known to impact different aspects of fish life-histories. In addition, loss of glaciers to maintain base flows will affect some systems, while loss of snowpacks will affect others. All systems, particularly the rain dominated ones, will likely be affected by the increased magnitude and frequency of major storm events. Channel disruptions can degrade, destroy or cutoff access to habitat (spawning, rearing, etc.), and peakflow events associated with large storm events can increase overwintering mortality in eggs and fry. The cascading impacts of potentially losing salmon from some of these systems are huge, both to human populations and to other ecological elements, including grizzly populations that depend on salmon to maintain their life histories. Nutrient flow through forests could also be disrupted.

Increased frequency and severity of storms may result in a significant increase in disturbance as has already been witnessed for landslides in some regions, and this may exacerbate the already-inflated level of landslides associated with harvest development. Downstream implications include impacts on human infrastructure and additional stresses and impacts to salmon and other aquatic species. Rainfall and mixed snow/rainfall dominated watersheds are likely most susceptible to these increased storm frequencies. Coastal transition areas and interior headwaters of some large coastal systems that drain the western edges of the Central Interior Region may see changes in flow regimes due to loss of forest cover in the headwaters.

Drier summer conditions may result in outbreaks of western hemlock looper. Spruce weevil (which attacks young Sitka spruce) is very sensitive to temperature changes, and increases of only 1^{o} are expected to allow weevil broods to develop. Significant areas on the coast that are not currently susceptible to weevil could therefore become so.

Overall: the coastal southern region is expected to see significant biodiversity impacts due to the magnitude of climate changes expected (particularly in comparison to natural variability) which are expected to affect natural disturbance frequencies, with drought and insect populations likely significant. Adaptation potential is expected to be reduced by the high stress on this system existing already from a variety of pressures. Climate change is expected to have a lower impact on forested ecosystems on most of the more exposed part of the coast. However, impacts on aquatic systems are expected to be very high. Impacts particularly on cold-water fish species may be exacerbated by on-going harvesting which can increase the rate at which aquatic systems respond to air temperature increases.

Northern Interior

This region is a complex of mountain and plateau landscapes. There are extensive lakes and wetlands and a few major river systems. There is generally a low density of human populations distributed across the landscape. The Peace River area has significant agricultural and oil and gas development while other areas have limited forestry development. The Muskwa-Kechika and Spatzizi plateau areas are well known for having significant numbers and distribution of large mammals, and a largely intact predator - prey systems.

Temperatures are expected to increase more across the northern region of BC, especially in the winter, than any other part of BC. Increases in winter precipitation across the whole region are also expected to be the largest in BC. In the summer, large precipitation increases are expected in the west and central portion of the region, but are predicted to be negligible to negative in the southeastern Peace River portion of the region.

In the western portion of the region, the climate shift is expected to result in an almost complete disappearance of the climatic envelope of the current SWB zone within 100 years and an expansion of warmer, moister forests dominated by subalpine fir and/or various hardwoods, likely somewhat similar to some parts of the ESSF. Invasive plant species are considered of lower threat here, so some grasslands may remain in reasonable condition into the future. Alpine tundra ecosystems are expected to disappear over time due to increasing encroachment by trees, but are more likely to become shrubby ecosystems in the short-term.

Natural disturbance dynamics in the western areas are expected to shift from relatively long return intervals to shorter intervals, resulting in an increase of younger forest on the landscape. The implications of climate change for regeneration in this (still) relatively harsh climate (currently, long periods are required for regeneration and multi-storied stands develop) is unknown.

The BWBS zone is also expected to see a significant shift in temperature limitations: it is one of the largest zones in the province and is expected to decline by about half within 85 years. The BWBS zone climatic envelope will likely remain in low elevations in the western portion of the region but will be replaced by drier warmer climates east of the Rockies. The ecosystems that replace the BWBS in the east will likely have correlates somewhere in south central Alberta rather than in BC. The disjunction of this region from climatically similar zones today raises significant issues as to how the ecosystems of this region will evolve through time.

In the eastern BWBS high or mixed severity fires dominate today, and fire frequency and severity are expected to increase, possibly doubling in area as a result of warming trends combined with decreased summer precipitation (Krawchuck et al. 2009). This may combine with increased movement of insects into this zone, causing the potential for larger fires (e.g., ongoing MPB and spruce bark beetle outbreaks in the Yukon). Some of the largest fires in BC's history have been recorded in this zone, and this could increase in future.

Rising temperatures will likely result in the melting of all permafrost in the discontinuous permafrost portion of the region, and significant thinning and possibly fragmentation of permafrost in other areas. This will likely create seedbed and stability problems for newly establishing forest stands, as well as for human structures and local hydrologic regimes. Landslides will increase in some areas due to loss of permafrost. Temperature increases may be offset by increases in snowfall that may also limit glacial retreat in some areas.

Lakes and rivers will freeze later in the autumn and thaw earlier in the spring, affecting aquatic habitats and terrestrial migration routes. Warmer water temperatures may increase aquatic productivity in some cases. Effects on arctic fish species are largely unknown, although the potential introduction of new parasites is of concern. Increases in landslides may decrease water quality locally. Changes in snowfall will affect the abundance and distribution of ungulates, and increased summer temperatures will likely increase insect-borne disease, parasites and insect harassment.

Overall: Climate change impacts are expected to have a variable impact on ecological values in this region. Large-scale forest disturbance processes are not expected to change significantly, but the magnitude of climate change is large (much higher than the global average) and is expected to shift climatic envelopes significantly. The ability of these systems to adapt are unknown given the extent of the likely shifts in biogeoclimatic zone climate envelopes. Significant changes such as permafrost melting are also likely to substantially impact soil processes and hydrology. In areas affected by the cumulative impacts of agriculture, forestry and oil and gas development, natural adaptation is likely to be more problematic than those areas that have been less impacted.

Central Interior

The central interior plateau region is an area of plateau/ mountain country with relatively low forest diversity. Many small and a few very large lakes span the region. A relatively low density human population exists across the landscape. Agriculture / ranching is expansive in some areas, and forestry development has occurred over the vast majority of the region. This region has been the focus of the mountain pine beetle epidemic and vast areas of this forest have had significant tree mortality. Harvest and now salvage harvest have rapidly increased the rate of forestry development in some areas.

Temperatures, particularly in winter, are predicted to increase across the region with greater increases in the northern portion. Precipitation is also expected to increase, again with most increases coming in the winter and generally in the northern portion of the region. Southern portions of the region will have little or no summer increases in precipitation ï though there are high uncertainties around precipitation predictions. Due to the relative lack of relief in this region, adaptation potential may be lower than in other regions because upslope shifts are not possible. Climatic envelope movement will require shifts of hundreds of kilometers across the landscape.

Two of the dominant zone envelopes in the region, the SBS and SBPP are projected to be reduced by over 80% under some scenarios. The southern portion of the region will likely see dramatic expansion of the grasslands as the BG and PPBG zones expand out of the Fraser Canyon. The IDF zone, or something similar will expand into much of what is now SBPS and lower to mid-elevation portions of the SBS. In the eastern and northern portions of the region, with increases in temperature and precipitation may shift from SBS to something more similar to the ICH.

Ecological shifts of this magnitude will not occur immediately, but they will also not occur without major ecosystem disruptions. Although the SBS has a reasonable floristic similarity to the ICH (56%), its similarity to the IDF and PP is less (33% and 10% respectively). The lack of local seed sources from many of the species that are likely to be climatically adapted to the shifting climatic conditions, means that as local species are increasingly stressed and lost to mortality, invasive species will likely become more problematic. Tree species that can reproduce vegetatively such as aspen and cottonwood may be favoured, as well as those more adapted to increased fire frequency such as lodgepole pine and Douglas-fir. The limited number of tree species in this region further reduces adaptation potential, and possibly future ecosystem resilience.

As trees become more maladapted to local climate conditions, species-host relationships for pathogens change, and insect outbreaks become more common all of which cause tree mortality to increase. The MPB outbreak may only be the opening act. Western spruce budworm is already expanding its range into new warming areas in this region. Douglas-fir beetles are taking advantage of trees already stressed by spruce budworm and increased summer drought. There is some evidence that past harvesting and silvicultural practices have contributed to increased spruce budworm activity. Spruce beetle outbreaks may also increase with warming temperatures and increased blowdown due to increasing frequency of major wind storms. Warming temperatures may allow spruce beetles to shorten their life cycles from two years to one, allowing populations to expand much more rapidly. In the northwest corner of the central interior increased summer precipitation has likely contributed to outbreaks of Dothistroma needle blight in stands of lodgepole pine. This may become a growing problem all across the northern portion of this region.

Increased tree mortality due to drought and insect outbreaks, combined with increased summer temperatures may also increase the frequency and intensity of fires. Major disturbance events, like stand-replacing fires, will be the ultimate drivers in the ecological shifts described above. The major question for this region is what seed sources will be available to repopulate ecosystems following disturbances.

Although overall precipitation may increase in much of the region, warming winter temperatures may result in decreased snowpacks and decreased summer low flows. Watersheds in plateau country may also be more susceptible to rapid spring snowmelts where they coincide with the upland elevations of the watershed. Watersheds in the east portion of the region will also be susceptible to flow reductions due to loss or glaciers over the medium- and long-term.

Salmon spawning drainages in the region that are close to tolerable temperature limits at present will be susceptible to increased water temperatures resulting in added stress and mortality on spawners. Decreased low flows and potential loss of ephemeral streams may also limit aquatic habitat. Loss of forest cover due to pests and fire may amplify the stream temperature changes. Increased frequencies and magnitudes of storms may also increase sedimentation and stream channel disturbances. Many wetlands will be at risk due to increased drought and evaporative demand.

Overall: this region is perhaps the canary in the coalmine regarding the on-coming effects of climate change. The combined effects of climate change and landscape condition resulting from human fire suppression have resulted in a massive mortality with yet to be fully understood ecological and socio-economic impacts. Such an outbreak was largely unimaginable, yet has swept through this region at amazing speed and with little warning. The resilience of the ecosystem has likely been affected, particularly given the extent of salvage harvesting, and many additional impacts are expected in future including changes in disturbance regimes and increases in other forest health species.

3.0 POTENTIAL MANAGEMENT RESPONSES

Responding to the challenges posed by climate change can take a variety of forms, but three main classes of response are outlined in the IPCC reports:

- conduct iterative and integrated vulnerability assessments to better understand the potential impacts, vulnerabilities and adaptive capabilities within the forest and range sector;
- design and implement an adaptation strategy to reduce impacts and improve adaptive capacity; and,
- design and implement a mitigation strategy to reduce contributions to GHG emissions that are driving climate change.

The IPCC and other authors have recommended that all of these options be balanced within a risk management framework (e.g., Spittlehouse 2005, Parry et al. 2007, Lemmen et al. 2008). As shown in Figure 2, adaptation is only effective with lower levels of climate change, and maybe only in the short-term if climate change continues unabated. Mitigation provides benefits over the medium and long-term by preventing the more serious impacts that are associated with higher levels of global temperature increases. Adaptation can be applied at local and regional scales and is the primary focus of this project. However, mitigation strategies alone will determine the long-term future, and these will require coordinated global efforts, including all carbon managers (all emitters and sequestrators). Mitigation strategies therefore have the potential to be undermined by the ótragedy of the commonsô philosophy that has affected international talks to date. It cannot be over-stated that without significant mitigation efforts, attempts at adaptation ï for many ecological and social systems ï will be futile.

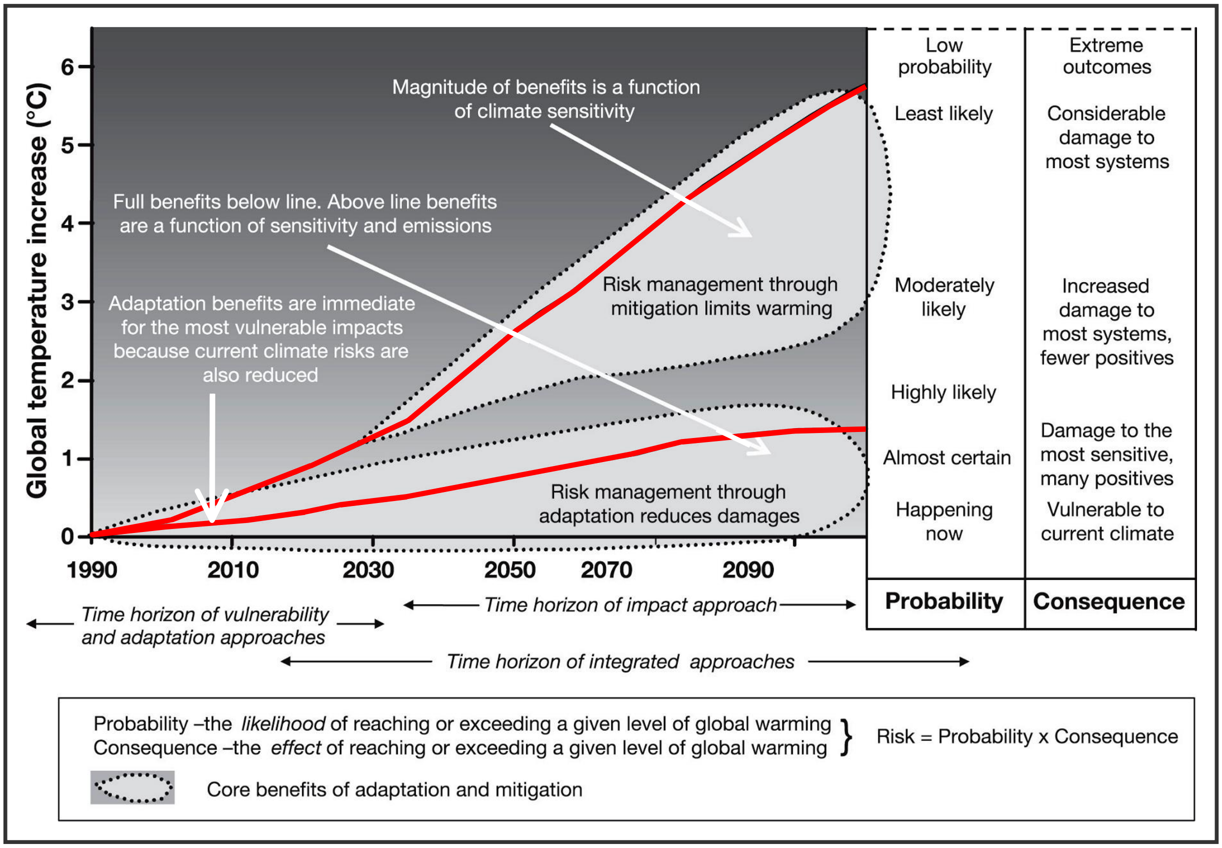


Figure 2. A synthesis of risk management approaches to climate change. The two red lines show the projected range of global warming based on scenario modelling of projected GHG emissions. The two gray shaded blobs schematically indicate the zones of maximum benefit for adaptation and mitigation. The two right columns show the likelihood of various levels of climate change and associated consequences for assessing various alternatives or integrated strategies within a risk assessment framework.

3.1 Vulnerability Assessments

Vulnerability assessments are a means of assessing the degree to which systems are susceptible to ,or unable to cope with, adverse effects of climate change (for more information see Appendix 2). An assessment must consider the exposure of the system to climate change (character, magnitude and rate), the sensistivity of the system and its capacity to adapt (IPCC 2007b glossary). The assessment provides a basis for decision-making regarding the pursuit of adaption and mitigation policies and actions. This report provides a first step in the development of a full-scale vulnerability assessment for forest and range ecosystems in BC by providing an initial estimate of the potential impacts of climate change. However, significantly more work is required to fully develop a complete and integrated vulnerability assessment. The main components of a vulnerabiliy asessement are briefly described below.

Exposure: Preliminary climate predictions are available for B.C. (Spittlehouse 2008, Rodenhuis 2008), and significant work is on-going to increase the spatial resolution of the predictions and better quantify a wider range of relevant climatic variables (particularly relating to variability and extreme events). Although there will always be uncertainty regarding the potential exposure, a range of models can be utilized to provide "bookends" to at least define a reasonable range of plausible alternatives.

Sensitivity: A weak link in the assessment process is our limited understanding of the potential responses of the various ecosystems, ecosystem components, ecosystem processes, and potential disturbance mechanisms to a given exposure to climate change ï i.e. their sensitivity to climate change. Understanding the details involved in these interactions is further complicated by current and future cumulative effects from on-going land management activities. Understanding these interactions for critical impacts will continue to be key as response policies evolve.

Adaptive Capacity: A vulnerability assessment should also consider the adaptive capacity of the ecosystems and ecosystem components. Ecosystems and ecosystem components have an inherent ability to withstand or adapt to change. Adaptive capacity may be reduced by stresses resulting from past human activities, or potentially improved by management actions we may choose to take in the future. Little information on ecological adaptive capacity exists today.

Integration: The final stage of the vulnerability assessment is to integrate biophysical assessments with socio-economic assessments. Integrated assessments generally engage a full suite of stakeholders to ensure that information regarding vulnerability and adaptation is fully informed of historic management interactions and present socio-economic realities. Although our understanding of processes linking ecosystem services to basic ecological functions are generally weak, disruption of such processes - such as the MPB outbreak ï can provide stark reminders of the linkages between human systems and ecosystems. The Kamloops Future Forest Project (http://www.for.gov.bc.ca/hcp/ffs/kamloopsFFS.htm) provides a useful starting point for such an assessment; by substantially broadening its scope it could be expanded into a fully integrated assessment.

3.2 Adaptation

Although this report is focused on forest and range ecosystems, adaptation is generally considered at multiple levels, including both ecological systems and human systems. Understanding complex interrelationships between ecological sytems and human systems generally requires careful consideration of both systems simulaneously. Developing adaption policies and strategies will therefore be an iterative process because we need to act now, even in the face of incomplete knowledge. As our knowledge base increases, policies and strategies can be refined.

Adaptation actions can reduce some impacts of climate change and reduce future vulnerabilities if employed appropriately and in a timely fashion. Their success depends partly on a thorough understanding of climate change exposure and anticipated system responses, or on appropriate application of a risk management strategy when full understanding is not possible. Some ecological impacts cannot be avoided through adaptation strategies: melting of mountain glaciers or loss of coastal margins to rising sea levels for example. Adaptation policies are also more feasible where changes are of limited magnitude and / or are occurring at slower rates (see Figure 2).

The literature has recently expanded with many discussions of what ecosystem adaptation policies should aim for. There are no silver bullets ï and in fact much of what is recommended is not much different from what has always been environmentally sustainable land management (e.g., Noss 2001; Millar et al. 2003; Hansen et al. 2003; FSP-BCFS 2008, CCSP 2008). Broad principles include those described by the FFEI technical team (FFEI technical team et al., 2008):

A. Overarching Principle:

Ecological Resilience *– Resilient ecosystems have an inherent capacity to withstand, recover from, or adapt to perturbations and changing environmental conditions so as to maintain key structures, processes and functions.*

<u>*Rationale:*</u> *Rapid climate change will significantly stress British Columbia's forest and range ecosystems. The magnitude of change that an ecosystem can absorb before the system changes into a qualitatively different state controlled by a different set of processes depends on*

its level of ecological resilience. Therefore, the Future Forests Ecosystems Initiative will focus its work on adapting our management framework to support the capacity of ecosystems to be resilient and able to continue to provide goods and services.

B. Supporting Principles:

Change and uncertainty *– Ecosystems are not static; they are dynamic and change in response to the continuous interactions among the individual ecosystem components.*

> *Rationale:* *Ecosystems are complex and their individual components, e.g. species, are continuously reacting to each other and to the environment resulting in the ongoing modification of these systems. We must shift from thinking of ecosystems (at all levels) as stable predictable entities to systems experiencing continual change in potentially new and unpredictable directions.*

Adaptive Capacity *– Adaptive capacity confers resilience.*

> *Rationale: The key to resiliency is adaptive capacity i.e., the potential for a species or system to respond, recover from and adapt to perturbations and changing environmental conditions, including changes in variability and extremes.*

Diversity *– Diversity (e.g., biological diversity) contributes to resiliency by enabling a wider variety of responses and capacities to adapt and evolve.*

> *Rationale: Natural variability at all levels – within species (genetic) diversity, diversity of species within guilds (functional groups), structural complexity, diversity of habitats and landscapes through time and space – contributes to the resiliency of ecosystems.*

C. Resource Management Principles:

Process Focus *– Focus on understanding the system as a whole, the system components and the relationships among the components, including:*

- *The processes (e.g., hydrological, natural disturbance regimes etc.) that connect system components at various scales across the landscape, and*
- *The effects of management practices on those processes.*

> *Rationale: Ecological systems are complex. They are characterized by nonlinear feedback loops that operate at varying scales through time across the landscape. This makes it extremely difficult to identify when a system will cross a threshold that causes rapid transition to a new state. It also makes it difficult to predict what the new state will be. Managing to reduce the vulnerability of one specific system component (e.g., a single species) to climate change is likely to increase the vulnerability of other components or increase the future vulnerability of the system as a whole.*

Cumulative Effects *– Acknowledge that the condition of an ecosystem and its capacity to adapt declines with each successive disturbance.*

> *Rationale: Human land-use activities have varying effects on ecosystem structure and function and can be expected to exacerbate the effects of climate change. In a time of rapid climate change it is prudent to minimize stress-inducing activities and focus on understanding the conditions under which thresholds are likely to be crossed causing a rapid shift in ecosystem state.*

***Continuous Learning and Responsive Management** – Continuously learn about changing conditions and the effects on ecosystems and iteratively review, evaluate and adjust management strategies to reflect new knowledge and circumstances.*

> *Rationale: Management during times of rapid change and uncertainty needs to include an iterative process whereby decisions and practices are regularly and frequently reviewed and adjusted in light of new information about the state of the system and the key processes and functions that confer resilience. An ongoing effort to develop models, monitor change, regularly and iteratively assess vulnerability, and study ecological processes, functions and the impacts of stress will provide the knowledge base to improve our ability to characterize uncertainty and predict and manage for the future.*

Additional principles include:

- Slow the rate of change and aid natural adaptation – maintain critical habitats, connectivity, stand level functions, etc;
- Change the management paradigm from "command and control[4]" to maximizing future options to cope with the unknown; and,
- Broaden engagement and collaboration; and,
- Enhance institutional capacity to implement, promote, and where appropriate, mandate adaption measures (Lemmen et al. 2008).

Since humans interact with ecosystems through management activities, the primary lever we have is to alter how we manage those activities. Although BC forest and range management directly affects a relatively small amount of BC annually, the cumulative impacts over time are significant, and impacts are extensive and concentrated in the most productive portions of the landscape. Some significant steps could be taken in those areas to maintain or possibly increase ecosystem adaptive capacity.

A U.S. Environmental Protection Agency (EPA) report reviewing adaption options for ecosystems and resources that may be sensitive to climate change defined adaption as "adjustments in human social systems (e.g., management) in response to climate stimuli and their effects" (CCSP 2008, p.1). To better identify synergies and barriers to implmentation of adaptation options, the EPA found it useful to examine adaptation within the context of the objectives and goals of each management organization.

The key messages coming from the EPA review are summarized below (CCSP 2008, p.1-4):

- *Many existing best management practices for "traditional" stressors of concern have the added benefit of reducing climate change exacerbations of those stressors (e.g., riparian buffers) – some practices may require adjustments*
- *Seven "adaptation approaches" can be used for strategic adjustment of best management practices to maximize ecosystem resilience to climate change:*
    - *Protection of key ecosytem features – maintenance of keystone areas, structures and/or organisms*
    - *Reduction in anthropogenic stresses – minimization of human stressors (e.g., fragmentation)*
    - *Representation – full representation of ecosystems in protected areas*

[4] As discussed in Holling and Meffe 1996.

- *Replication – redudancy in conservation areas*
- *Restoration – rehabilitation of ecosystems previously compromised*
- *Refugia – protection of areas less affected by climate change*
- *Relocation – i.e. assisted migration.*

- *Levels of confidence in these adaptation approaches vary and are difficult to assess, yet are essential to consider in adaptation planning – two elements of uncertainty: 1) amount of available evidence; 2) level of agreement throughout the scientific community regarding effectiveness of an adaption approach (at present there is high confidence in the ability of reducing anthropogenic stress to promote resilience, varying confidence in other measures, and minimal confidence in relocation).*
- *The success of adaptation strategies may depend on recognition of potential barriers to implementation and creation of opportunities for partnerships and leveraging – cooperation and coordination among stakeholders will be critical to success.*
- *Adaptive capacity can be increased through expanded collaborations among ecosystem managers – need for cooperation and coordination with adjacent management units to appropriately manage large landscapes and take advantage of information sharing.*
- *Adaptive capacity can be increased through creative re-examination of program goals and authorities – need for dynamic management systems that can continually accommodate change through periodic adjustments to priorities, plans and in some cases their basic mandates.*
- *Establishing current baselines, identifying thresholds, and monitoring for changes will be essential elements of any adaptation approach – and using this information with scenario modeling to assess future risks.*
- *Beyond "managing for resilience," the capability to adapt will ultimately depend on our ability to be flexible in setting priorities and "managing for change" - over time, the ability to "manage for resilience" of current systems in the face of climate change will be limited as temperature thresholds are exceeded, climate impacts become severe and irreversible, and socio-economic costs of maintaining existing ecosystem structures, functions, and services become excessive. At this point, it will be necessary to "manage for change,"*

Forest and range infrastructure and economic investment is also vulnerable to the impacts of climate change (Johnston et al. 2006, Lempriere 2008). The need for timely implementation of adaptation strategies has been demonstrated already with the loss of timber resources due the mountain pine beetle infestation. Increases in the magnitude and frequency of storm events will have growing impacts on roads systems over the coming years (Guthrie et al. In press). Adaptation in timber supply management, harvest planning, silviculture and road construction standards will clearly be required as climate change intensifies (Spittlehouse 2005).

3.3 Mitigation

The data are clear ï even with the huge uncertainties involved in climate predictions, we cannot afford to exceed some of the lowest level potential impacts of climate change. This requires significant buy-in from everyone everywhere, to reduce GHG emissions today and work towards mitigating the scope of future climate change. Therefore, considering policy changes in relation to adaptation strategies should not be done without consideration of climate change mitigation (see Figure 2).

Work is underway to understand the role of forests in carbon emissions. The news is not positive ï many of the projected impacts of climate change may exacerbate carbon emissions from forests ï through increased insect and disease damage, faster rates of decay, and increased fire frequencies and severities province-wide (Kurz et al. 2008). This alone provides additional impetus for mitigation strategies that attempt to reduce some of these catastrophic events.

However, other forests in BC are less prone to disturbance, and store some of the highest levels of carbon biomass in Canada and the world (Smithwick et al. 2002; Wilson and Hebda 2008; Trofymow et al. 2008). Considering how policies can synergistically work together towards an integrated climate change strategy will provide the most benefits - now and into the future (Ravindranath 2007, Parry et al. 2007).

3.4 Risk Management

A risk management approach attempts to incorporate information on potential impacts and consequences of climate change, the potential benefits of various adaptation and mitigation strategies, while simultaneously addressing uncertainty at all levels of climate change assessment. Risk is generally measured as the combination of the probability of an adverse event, and the severity of the consequences of that event. Risk management is defined as "the systematic application of management policies, procedures and practices to the tasks of analyzing, evaluating, controlling and communicating about risk issues" (CSA 1997), or "the culture, processes and structures directed towards realizing potential opportunities whilst managing adverse effects" (AS/NZS 2004). Outcomes of risk management approaches to climate change can be presented either qualitatively and quantitatively, and also allow for the simultaneous consideration of both adaptation and mitigation options.

Application of a risk management framework builds on the results of a vulnerability assessment by providing a structure within which to evaluate alternative policies and actions in light of the outcomes of the assessment. The main advantage of the risk assessment framework is that it allows for structured decision-making in the face of significant uncertainty. Combining risk management with adaptive management provides a framework for continual reassessment and adjustments to policies and actions as climate change intensifies and new information becomes available (Lempriere 2008).

Succesful implementation of risk management and adaptive management programs will require significant increases in flexibility and increased investment in monitoring. Transparency, consultation and collaboration will become increasingly essential elements of planning to ensure that all forest sector stakeholders are informed and actively participating. Otherwise it will be difficult to develop the trust among stakeholders necessary to allow for the flexibility required for adaption in a coordinated and timely manner.

4.0 CONCLUSIONS

Climate change is with us and intensifying. Measured impacts are growing in number, and predicted impacts are immense and likely dramatic for many ecological systems. Although uncertainties are numerous and diverse, it is highly likely that forest and range ecosystems will be significantly impacted and those impacts will spread to the social and economic systems we have built around those ecosystems.

For those engaged in management of forest and range ecosystems in BC, climate change provides a new context for decision-making. Wait-and-see approaches are no longer recommended. Climate change mitigation and adaptation should be central to all decisions – at all levels.

As the IPCC (2007a, p.65) states:

> *There is **high confidence** that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilization scenarios*

assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change.

While mitigation is needed to reduce the likelihood of long-term catatrophic impacts, adaptation policies are needed immediately to reduce vulnerabilities and minimize impacts that are occurring now and unavoidable in the short- to medium term. Given the potential magnitude of the consequences and the level of uncertainty, decisions about possible policies and actions should be taken within the framework of a broad-based and transparent risk assessment framework, while simultaneously considering the implications of the precautionary principle on each option. The scope of the potential impacts requires a response of appropriate magnitude: not business-as-usual with a few tweaks, but likely a new management paradigm yet to be defined.

Effective evaluation and deployment of adaptation and mitigation measures will require the identification and treatment of potential institutional barriers. Such barriers may include lack of access to knowledge, data and decision-support tools, or regulations and juridictional mandates that limit the ability of agencies to respond in a effective and timely manner (Lemmen et al. 2008). Assessment, planning and decision-support tools will have to be updated and/or developed to incorporate climate change issues at all levels of decision-making ï ñmainstreamingò (Lemmen et al. 2008, Lempriere et al. 2008).

Although the risks are high, this is also an exciting time to be a resource manager ï the decisions taken now will likely be some of the most important in the history of resource management. It is an opportunity where independent thought and new ideas are not only welcomed, but demanded.

5.0 REFERENCES

Araujo, M.B and C. Rahbek. 2006. How does climate change affect biodiversity. Science 313: 1396-1397.

AS/NZS. 2004. Risk Management. Australian/New Zealand Standard for Risk Management. AS/NZS 4360:2004. 38 pp.

Aulisi, A., Sauer, A., and Wellington. 2008. Trees in the Greenhouse: Why Climate Change is Transforming the Forest Products Business. World Resource Institute, Washington, DC. 74 pp.

Austin, M., D. Buffet, D. Nicolson, G. Scudder and V. Stevens (eds.). 2008. Taking Natureǿs Pulse: The Status of Biodiversity in British Columbia. Biodiversity BC, Victoria, BC. 268pp.

Austin, M.A., D.A. Buffett, D.J. Nicolson, G.G.E. Scudder and V. Stevens (eds.). 2008. Taking Natureǿs Pulse: The Status of Biodiversity in British Columbia. Biodiversity BC, Victoria, BC. 268 pp. Available at: www.biodiversitybc.org.

Beever, E.A., P.F. Brussard and J. Berger. 2003. Patterns of apparent extirpation among isolated populations of pikas (Ochotona princeps) in the Great Basin. J. Mammology 84: 37-54.

Bertram, D. 2001. Seabird reproductive performance as an indicator of climate variability. Canadian Institute for Climate Studies. Unpublished Report MoELP.

Blackstock, M.D. 2008. Blue ecology and climate change. BC Journal of Ecosystems and Management 9(1):12ï 16. url: http://www.forrex.org/publications/jem/ISS47/vol9_no1_art2.pdf

Blennow, K. and E. Olofsson. 2008. The probability of wind damage in forestry under a changed wind climate. Climatic Change 87:347ï 360

Brook, B.W., N.S. Sodhi and C.J.A. Bradshaw. Syngeris among extinctinon drivers under global change. Trends in Ecology and Evolution 23 (453-460).

Bunnell, F. 1995. Forest-dwelling vertebrate faunas and natural fire regimes in British Columbia: Patterns and Implications for Conservation. Cons. Biol. 9 (3) 636-644.

Bunnell, F. and K. Squires. 2005. Evaluating potential influences of climate change on historical trends in bird species. A report for MoELP, Province of B.C.

Campbell, E., D. Meidinger, S. Saunders, A. MacKinnon, C. Delong, B. Rogers, D. MacKillop, G. O'Neil, , D, Spittlehouse and F. Njenga. 2008. Implications of Climate Change on Ecosystems. DRAFT Upubl. Report. Forest Science Program, BC Forest Service. Victoria, BC.

Canadell, J.G. , C. Le Quéré, M.R. Raupach, C.B. Field, E.T. Buitenhuis, P. Ciais, T.J. Conway, N.P. Gillett, R.A. Houghton, and G. Mar. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity and efficiency of natural sinks. Proc. Nat. Acad. Sci.: www.pnas.org/cgi/doi/10.1073/pnas.0702737104.

Canadian Standards Association. 1997. Risk Management: Guidelines for Decision-Makers. Canadian Standards Association. Etobicoke, ON. 46pp.

Caprio, J., H. Quamme and K. Redmond. 2009. A statistical procedure to determine recent climate change of extreme daily meteorological data as applied at two locations in Northwestern North America. Climatic Change (92)1-2:65-81.

Carpenter, K.E., M.Abrar, G.Aeby et al. 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321(5888): 560-563.

Carter, T.R., R.N. Jones, X. Lu, S. Bhadwal, C. Conde, L.O. Mearns, B.C. O'Neill, M.D.A. Rounsevell and M.B. Zurek. 2007. New Assessment Methods and the Characterisation of Future Conditions. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 133-171. WG II Chpt. 2.

Climate Change Science Program. 2008. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Julius, S.H. and J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.

Committee on the Status of Pollinators in North America. 2007. Status of Pollinators in North America, Board on Life Sciences, Board on Agriculture and Natural Resources, Division on Earth and Life Studies, National Research Council of the National Academies. National Academies Press. Washington, D.C. 312pp.

Compass Resource Management. 2007. Major Impacts: Climate Change. Prepared for BBC Technical SubCommittee. Available at: www.biodiversitybc.org

Couture, N.J. and W.H. Pollard. 2007. Modelling geomorphic response to climatic change. Climatic Change 85:407-431.

Dale, V.H., L,A. Joyce, S. McNulty and R.P. Neilson, 2000. The interplay between climate change, forests, and disturbances. The Science of the Total Environment 262:201-204.

FFEI Technical Team, Hamilton, E., and Niemann, T. 2008. Future Forest Ecosystem Initiative Technical Team 2008/2009 Workplan.

Foden, W., Mace, G., Vié, J.-C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. 2008. Species susceptibility to climate change impacts. In: J.-C. Vié, C. Hilton-Taylor and S.N. Stuart (eds). The 2008 Review of The IUCN Red List of Threatened Species. IUCN Gland, Switzerland.

Forest Practices Board 2007. The effect of range practices on grasslands: a test case for upper grasslands in the south central interior of British Columbia. FPB/SIR/19.

Forest Science Program, BCFS. 2008. Manageing forest ecosystems in an era of rapid climate change: a theoretical foundation for the Future Forest Ecosystems Initiative of BC – Draft, July 2008. Bc MoFR. Vicotia, BC. 20pp.

Gayton, D. 2008. Impacts of climate change on British Columbia's Biodiversity. A literature Review. Forrex Series 23.

Grassl, H., J. Kokott, M. Kulessa, J. Luther, F. Nuscheler, R. Sauerborn, H.J. Schellnhuber, R. Schubert, E.D. Schulze. 2003. Climate Protection Strategies for the 21st Century: Kyoto and beyond. German Advisory Council on Global Change (WBGU). Berlin, Germany. 77pp.

Guthrie, R.H., S.J. Mitchell, N. Lanquaye-Opoku, and S.G. Evans. In press. Landslides and extreme weather: impacts of rain, wind and temperature on landslide initiation in coastal mountain watersheds Submitted to: Quarterly Journal of engineering Geology and Hydrology.

Hall, M.H.P. and Fagre, D.B., February 2003. Modeled Climate-Induced Glacier Change in Glacier National Park,1850-2100. BioScience, 53(2): 131-140.

Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87:2773–2786.

Hannah, L, G.F. Midgley, T. Lovejoy, W.J. Bond, M.Bush, J.C. Lovett, D. Scott and F.I. Woodward. 2001. Conservation of biodiversity in a changing climate. Cons. Biol. 16 (1) 264-268.

Hansen, J. E. 2005. A slippery slope: How much global warming constitutes "dangerous anthropogenic interference"?. Climatic Change 68(3):269-279.

Hansen, L.J., J.L.Biringer and J.R. Hoffman. 2003. Buying Time: A user's manual for building resistance and resilience to climate change in natural systems. Published by WWF.

Hare, W.L. 2006. Relationship Between Increases in Global Mean Temperature and Impacts on Ecosystems, Food Production, Water and Socio-Economic Systems. In: Schellnhuber, H.J. (ed.) Avoiding Dangerous Climate Change. Cambridge University Press, Cambridge CB2 2RU, UK

Hawkes, B. and Flannigan, M. 2005. Climate change and forest fire in British Columbia. In Conference proceedings: Implications of climate change in British Columbia's southern interior forests. April 26–27, 2005 in Revelstoke, BC. Columbia Mountains Institute, Revelstoke. url: http://www.cmiae.org.

Hennon, P.E., D.V. D'Amore, S. Zeglen and M. Grainger. 2005. Yellow-Cedar Decline in the North Coast Forest District of British Columbia. USDA Forest Service. Research Note PNW-RN-549. 16pp.

Henry, H.L. 2008. Climate change and soil freezing dynamics: historical trends and projected changes. Climatic Change 87: 421–434.

Hobbs, R.J., S. Arice, J.Aronson et al. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecol. Biogeogr. 15: 1-7.

Holling, C.S., and G.K. Meffe. 1996. Command and control and the pathology of natural resource management. Conservation Biology 10: 329-337.

Holt, R.F. 2001. A strategic ecological restoration assessment (SERA) in the forest regions of British Columbia. The results of six workshsop. Prepared for MoE through FRBC.

Holt, R.F., G. Utzig, M. Carver and J. Booth. 2003. Biodiversity Conservation in BC: An Assessment of Threats and Gaps. Prepared for MoELP. Available: www.veridianecological.ca

Inouye DW, Barr B, Armitage KB, Inouye BD. 2000. Climate change is affecting altitudinal migrants and hibernating species. *Proc. Natl. Acad. Sci. USA* 97:1630–33

Intergovernmental Panel on Climate Change. 2007a. Climate Change 2007: Synthesis Report. This report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report. 73pp.

Intergovernmental Panel on Climate Change. 2007b. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Jones, C. and C. Brown. 2008. ClimateBC Modeling and Future Ecosystem Climate Mapping (Version 2.0). Unpubl. Report for: Kamloops TSA Future Forest Strategy. BC MoFR. Research Branch. Victoria, B.C. 39pp.

Jones, R.F. 2001. An environmental risk assessment / management framework for climate change impact assessments. Natural Hazards 23 (2-3_ 197-230.

Klein, A-M, B.E. Vaissière, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B. 274:303-313.

Krawchuk, M.A., S.G. Cumming and M.D. Flannigan. 2009. Predicted changes in fire weather suggest increases in lightning fire initiation and future area burned in the mixedwood boreal forest. Climatic Change 92:83ï 97

Kurz, W., Stinson, G., Rampley, G.J., Dymond,C.C., and Neilson, E.T. 2008. Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. PNAS 2008 105:1551-1555

Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather. 2007. Historical Overview of Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. WG I Chpt. 1.

Lemmen, D.S., Warren, F.J., Lacroix, J. and Bush, E. editors. 2008. From Impacts to Adaptation: Canada in a Changing Climate 2007. Government of Canada, Ottawa, ON. 448pp.

Lemprière, T.C., Bernier, P.Y., Carroll, A.L., Flannigan, M.D., Gilsenan, R.P., McKenney, D.W., Hogg, E.H., Pedlar, J.H., Blain, D. 2008. The importance of forest sector adaptation to climate change. Nat. Resour. Can., Can.For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-416E.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao. 2007. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. WG I Chpt. 10.

Michels, A., Laird, K.R., Wilson, S.E., Thomson, D., Leavitt, P.R., Oglesby, R.J., Cumming, B.F. 2007. Multidecadal to millennial-scale shifts in drought conditions on the Canadian prairies over the past six millennia: implications for future drought assessment. Glob. Chang. Biol. 13:1295ï 1307.

Millar, C.I., N.L. Stephenson and S.L. Stephens. 2007. Climate change an forests of the future: managing in the face of uncertainty. Ecological Applications, 17(8):2145ï 2151

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC. On the web: http://www.millenniumassessment.org/documents/document.354.aspx.pdf

Morgan, P., E. Heyerdahl and C. Gibson. 2008. Multi-season climate synchronized forest fires throughout the 20th Century, Northern Rockies, USA. Ecology 89(3): 717ï 728.

Nelitz, M., C. Alexander and K. Wieckowski. 2007a. Helping Pacific salmon survive the impact of climate change on freshwater habitats: Case Studies. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for Pacific Fisheries Resource Conservation Council, Vancouver, B.C. 67pp.

Nelitz, M., K. Wieckowski, D. Pickard, K. Pawley, and D.R. Marmorek. 2007b. Helping Pacific salmon survive the impact of climate change on freshwater habitats. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for Pacific Fisheries Resource Conservation Council, Vancouver, B.C. 128 pp.

Nitschke, C.R. 2008. Climate Change and the SBS. Upubl. Report for FFEI Technical Team. Forest Science Program, BC Forest Service. Victoria, BC. 8pp.

Nitschke, C.R. and J.L. Innes. 2008. Integrating climate change into forest management in South-Central British Columbia: An assessment of landscape vulnerability and development of a climate-smart framework. Forest Ecology and Management 256: 313-327.

Noss, R.F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. Conservation Biology. 15(3):578-590.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annu. Rev. Evol. Syst. 37: 637-69.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.

Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors. 2007. Technical Summary. Climate Change. 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78. WG II Tech. Sum.

Paul E. Hennon, P.E., D. V. DøAmore, S. Zeglen and M. Grainger. 2005. Yellow-Cedar Decline in the North Coast Forest District of British Columbia. USDA FS Research Note PNW-RN-549. 16pp.

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock and A.T. Werner. 2008c. A Summary of Climate Change Effects on Watershed Hydrology. B.C. Min. For. Range, Res. Br., Victoria, B.C. Exten. Note 87. http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En87.htm

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock, and A.T. Werner. 2008a. Climate change and watershed hydrology Part I ó Recent and projected changes in British Columbia. Streamline Watershed Management Bulletin. Vol. 11. No 2.

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock, and A.T. Werner. 2008b. Climate change and watershed hydrology Part II ó Hydrologic implications for British Columbia. Streamline Watershed Management Bulletin. Vol. 11. No 2.

Pimm, S. 2007. Biodiversity: climate change or habitat loss ó which will kill more species? Current Biology Vol18 (3). R1 17 ó R1 ó 19.

PIRC. 2008. Climate safety. In case of emergency é Published in the UK. Available at climatesafety.org

Preston, B.L., 2006: Risk-based reanalysis of the effects of climate change on U.S. cold-water habitat. Climatic Change, 76, 91-119.

Pringle, C.M. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. Ecol. Appl. 11(4): 981-998.

Pyke, C.R. 2004. Habitat loss confounds climate change impacts. Front Ecol. Environ. 2(4) 178-182.

Ramanathan V, and Y. Feng. 2008. On avoiding dangerous anthropogenic interference with the climate system: formidable challenges. Proc Natl Acad Sci USA 105:14245ó14250.

Ravindranath, N.H. 2007. Mitigation and adaptation synergy in forest sector. Mitig. Adapt. Strat. Glob. Change 12:843ó853

Ripple, W. J., and R. L. Beschta. 2003. Wolf reintroduction, predation risk, and cottonwood recovery in Yellowstone National Park. Forest Ecology And Management 184:299-313

Rodenhuis, D.R., Bennett, K.E., Werner, A.T., Murdock, T.Q., Bronaugh, D. 2007. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 132 pp.

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rozenzweig and J.A. Pounds. Fingerprints of global warming on wild animals and plants. Nature 421 57 – 60.

Sauchyn, D. and S. Kulshreshtha. 2008. Prairies. *In;* From Impacts to Adaptation: Canada in a Changing Climate 2007, e*dited by* D.S. Lemmen, Warren, F.J., Lacroix, J. and Bush, E. Government of Canada, Ottawa, ON. p.275-328.

Schindler, D.W.; Donahue, W.F. 2006. An impending water crisis in Canada's western prairie provinces. Proc. Natl. Acad. Sci. U.S.A. 103:7210–7216.

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yamin. 2007. Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 779-810. WG II Chpt. 19.

Sillmann, J. and E. Roeckner. 2008. Indices for extreme events in projections of anthropogenic climate change. Climatic Change 86:83–104

Smithwick, E.A.H., Harmon, M.E., Remillard, S.M., Acker, S.A.,and Franklin, J.F. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecol. Appl. 12(5): 1303–1317.

Solomon, S.. G. Plattner, R. Knutti and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. Proc. Nat. Acad. Sci. 2009 106:1704-1709; doi:10.1073/pnas.0812721106 http://www.pnas.org/content/106/6/1704.full.pdf+html?sid=61593260-7e62-418f-a345-94f08959ba86

Spittlehouse, D. 2008. Climate change, Impacts and Adaptation Scenarios: Climate Change and forest and range management in British Columbia. BC Ministry of Forests and Range, Victoria, British Columbia. Technical Report 45.

Spittlehouse, D.L. 2005. Integrating climate change adaptation into forest management. For. Chron. 81:691–695.

Stahl, K. and R.D. Moore. 2006. Influence of watershed glacier coverage on summer streamflow in British Columbia, Canada. Water Resources Research 42, W06201. doi: 10.1029/2006WR005022.

Stahl, K., R.D. Moore, J.M. Shea, D. Hutchinson, A.J. Cannon. 2008. Coupled modelling of glacier and streamflow response to future climate scenarios, Water Resources Research 44, W02422, doi:10.1029/2007WR005956.

Sterman, J.D. 2008. Risk communication on climate: mental models and mass balance. Science 322: 532-533. Available at: http://www.precaution.org/lib/mit_students_clueless.081024.pdf

Stevens, T. 2008. Personal Communication. Presentation given to ACT May 2008.

Taylor, S.W. and A.L. Carroll. 2004. Disturbance, forest age, and Mountain Pine Beetle outbreak dynamics in BC: a historical perspective. Pages 41-51 *in* Mountain Pine Beetle Symposium: Challenges and Solutions. October 30-31, 2003, Kelowna, British Columbia. T.L. Shore, J.E. Brooks, and J.E. Stone (editors). Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-399, Victoria, BC. 298 p.

Tebaldi, C., K. Hayhoe, J.M. Arblaster and G.A. Meehl. 2006. Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. Climatic Change 79: 185–211.

Thomas, C.D., A. Cameron, R.E. Green et al. 2004. Extinction risk from climate change. Nature 427(6970): 145-148.

Thomas, C.D., Cameron, A., Green, R.E.,Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson A., Phillips, O.L. and Williams, S.E. 2004. Extinction risk from climate change. *Nature* 427(6970): 145-148.

Trofymow, J.A., G. Stinson, W.A. Kurz. 2008. Derivation of a spatially explicit 86-year retrospective carbon budget for a landscape undergoing conversion from old-growth to managed forests on Vancouver Island, BC. Forest Ecology and Management 256:1677ï 1691.

Tschaplinski, P.J. 2009. Personal Communication. Email Feb 2009

van Mantgem, P.J., N.L. Stephenson, J.C. Byrne, et al. 2009. Widespread increase of tree mortality rates in the western United States. Science 23 323 521-524.

Visser ME, Both C. 2005. Shifts in phenology due to global climate change: the need for a yardstick. *Proc. R. Soc. B* 272:2561ï 69

Warren, M.S., J.K. Hill, J.A. Thomas, J. Asher, R. Fox, B. Huntley, D.B. Roy, M.G. Telfer, S. Jeffcoate, P. Harding, G. Jeffcoate, S.G. Willis, J.N. Greatorex-Davies, D. Moss, and C.D. Thomas. 2001. Rapid responses of British butterflies to opposing forces of climate and habitat change. Nature 414: 65ï 69.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan and T.W. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science 313(5789): 940-943.

Williams, J.W. and S.T. Jackson. 2007. Novel climates, no-analog communities, and ecological surprises. Front Ecol. Environ. 5(9): 475-482.

Wilson, S.J. and R.J. Hebda. 2008. Mitigating and adapting to climate change through the conservation of nature. Published by the Land Trust Alliance of B.C.

Wong, C., B. Dorner and H. Sandmann. 2003. Estimating historical variability of natural disturbances in British Columbia. LMH 53.

Woods, A., K.D. Coates and A. Hamann. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? BioScience 55(9):761-769

Woodwell, G.M. 2002a. On purpose in science, conservation and government: the functional integrity of the earth is at issue not biodiversity. Ambio, 31 (5), 432-436.

Woodwell, G.M. 2002b. The functional integrity of normally forested landscapes: a proposal for an index of environmental capital. Proceedings of the National Academy of Sciences of the United States of America. 99(21) 13600-13605.

Yohe, G.W., R.D. Lasco, Q.K. Ahmad, N.W. Arnell, S.J. Cohen, C. Hope, A.C. Janetos and R.T. Perez, 2007: Perspectives on climate change and sustainability. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge Univ. Press, Cambridge, UK, 811-841 WG II Chpt. 20.

APPENDIX 1: THE CONTEXT – CLIMATE CHANGE IS HERE AND INTENSIFYING RAPIDLY

In order to understand the context for consideration of adaptation strategies, this section provides a brief summary of climate change science to date.

A1.1 Evidence for Climate Change: Globally and Provincially

Climate change has been the subject of four major assessment reports from the International Panel on Climate Change, the most recent of which was released in late 2007 (IPCC 2007a). The fourth assessment report states:

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level,* [and that] *observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.* (IPCC 2007a, pp.30-31);
>
> *…...global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities,* [and] *… global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution.* (IPCC 2007a, p. 37).
>
> *……most of the observed increase in global average temperatures since the mid-20th century is **very likely**[5] due to the observed increase in anthropogenic GHG[6] concentrations* (IPCC 2007a, p. 39).

With regard to the magnitude and types of climatic changes the IPCC report states:

> **Temperatures:** *Temperatures of the most extreme hot nights, cold nights and cold days are **likely** to have increased due to anthropogenic forcing. It is **more likely than not** that anthropogenic forcing has increased the risk of heat waves…..*
>
> **Winds and Storm Events:** *Anthropogenic forcing is **likely** to have contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated by models in response to 20th century forcing change…..*
>
> **Precipitation including Extreme Events:** *There is some evidence of the impact of human climatic influence on the hydrological cycle, including the observed large-scale patterns of changes in land precipitation over the 20th century. It is **more likely than not** that human influence has contributed to a global trend towards increases in area affected by drought since the 1970s and the frequency of heavy precipitation events.* (IPCC 2007a, pp. 40-41)

Within British Columbia, records confirm that regional trends are consistent with the evidence at the global level. Rodenhuis et al. 2008 provide the following summary of important climatic trends over the past century:

[5] Specific terms of likelihood are defined as ranges of probability by the IPCC; for example, ñvery likelyò is defined as >90% probability based on expert judgement and statistical analysis.
[6] Greenhouse gas

B.C. Temperatures: increasing annual daily minimum temperature: +1.7°C (+1.0°C to +2.5°C per century)[7], increasing daily maximum temperature +0.6°C (+0.5°C to +1.5°C per century), and increasing daily mean temperature +1.2°C (+0.5°C to +1.5°C per century) have been documented. In northern BC minimum wintertime temperature trends were up to +3.5°C per century. For comparison, the global mean temperature trend is +0.7°C (between +0.6°C and 0.9°C per century).

B.C. Precipitation: trends for generally increased precipitation (+22% per century on average across BC) and some observations of +50% per century occurred in wintertime in the interior. However, there were exceptions, and some of the trends were reversed (negative) for shorter records (50 years).

A1.2 Climate Change Futures: Short- and Medium-Term

The prediction of future climates globally or provincially requires the use of complex assumptions regarding future GHG emissions, the relationship between GHG increases and atmospheric circulation, and the potential for various physical and biological feedbacks. The IPCC has prepared a series of scenarios with a suite of assumptions about population growth, socio-economic development and technological changes, and how those factors affect GHG emissions (Nakicenovic 2000). These scenarios project a range of GHG emissions, and can be used to predict a corresponding range of potential changes in global atmospheric circulation and climate over the coming centuries.

The recent IPCC (2007a) Fourth Assessment Report indicates that even if atmospheric CO_2 content could be stabilized at year 2000 levels, we are already committed to an average additional global surface warming of about 0.6^{O}C (see Figure 1). This is in addition the increase of roughly 0.7^{O}C that has already occurred over the 20th century. Even this seemingly small increase in temperature will result in significant adaptation challenges. The mountain pine beetle outbreak in BC provides a salient example of thresholds that can be surpassed with relatively small amounts of climate shift.

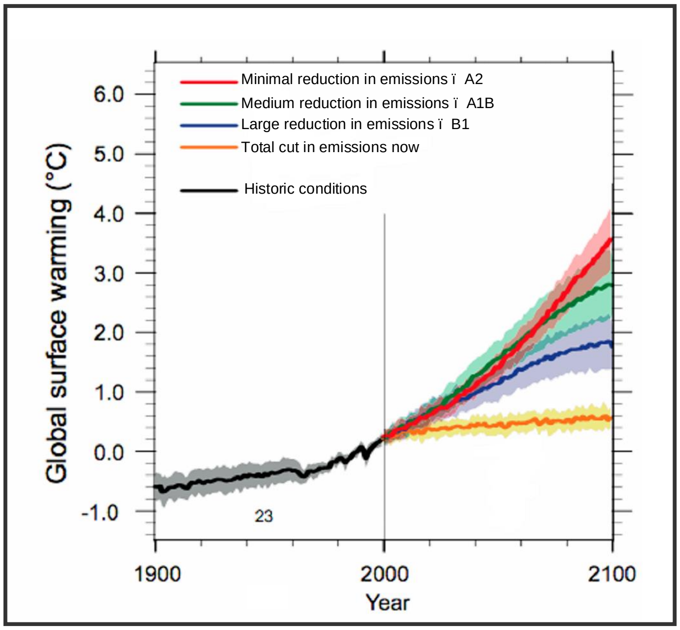


Figure A1. Multi-model means of global surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. The orange line is based on the assumption that GHG concentrations are held constant at year 2000 values. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means (from Meehl et al. 2007, p.762).

[7] The range in brackets indicates the geographical range of significant results for BC, based on the interval from 1900 to 2004, preceded by the average for BC.

Recent evidence however, points to the fact we have already surpassed year 2000 CO_2 levels, and have continued to increase our annual emissions (Canadell et al. 2007). Therefore we are already committed to at minimum, expanding climate change impacts for at least the next 40 years (the residence time of CO_2 in the atmosphere ï see Figure A1 ï total cut in emissions now). How large or for how long we have to deal with expanding climate change impacts will depend on the rate and extent of our GHG emission reductions. At present, there is significant uncertainty about whether any reductions are politically possible. Therefore future climate predictions must examine a range of future scenarios, with significant uncertainty as to which scenario will be the future we encounter.

A1.3 Climate Change Futures: Medium- and Long-Term

The outputs of selected global climate models have been used to illustrate potential climatic trends for BC, based on two of the IPCC scenarios ï A2 and B1 (Rodenhuis et al. 2008, Spittlehouse 2008, see Figure A1). Assumptions for the A2 scenario include a continuously increasing global population, with emphasis on regional autonomy, resulting in continuing regional disparities in economic growth and relatively slow uptake of new energy technologies. These assumptions lead to continually increasing carbon emissions over the next century ï essentially ñbusiness as usualò (Nakicenovic 2000). Under the B1 scenario global population peaks in the 2050s and then declines. Society makes ñrapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiativesò (Nakicenovic 2000, p.5). A third intermediate scenario, A1B, is also portrayed in Figure A1. This scenario assumes a growing global population that peaks in mid-century and then declines, increasing global social and economic cooperation, decreasing regional disparity, rapid economic growth and the rapid introduction on new and more efficient technologies. Under this scenario energy sources shift from heavy emphasis on fossil fuels to a balance between fossil and non-fossil sources (Nakicenovic 2000). Figure A1 displays the predicted influence of each scenario on additional global surface warming over this century. Both the A2 and B1 scenarios are predicted to cause significant changes in temperature and precipitation throughout the world, with A2 providing significantly higher impacts near the end of the century.

Using the Canadian Regional Climate Model (CRCM) and the ClimateBC downscaling tool, outputs from the global climate models have been downscaled to provide more detail for climate change projections in BC. The increased detail is a function of improved resolution of elevation and aspect in the downscaled results (Wang et al. 2006, Spittlehouse 2008, Rodenhuis et al. 2008). Figure A2 provides examples of downscaled climate maps for BC for the Canadian Regional Climate Model.

In addition to changes in temperature and precipitation, as both annual and seasonal means, significant increases in extreme weather events are also expected. Figure A3 shows predicted changes in the magnitude and frequency of extreme weather events, based on the A1B scenario (a middle-of-the-road scenario). Even at a global scale, BC can be seen to be an area predicted to have significant increases in the magnitude of high intensity precipitation events. The southern edge of BC is also projected to be an area with a potential increase in the consecutive number of dry days. Note that the changes in precipitation intensity are statistically significant for at least 5 of the 9 climate models used in the projections.

Many scientists are beginning to suggest that the important factor in weighing the choices for pursuing various mitigation options, is the likelihood of the option leading to temperature increases of over 2.0^{O}C (e.g., Grassl et al. 2003, Hare 2006, Hansen 2005). It is generally accepted that an average increase of over that level may lead to global systems feedback mechanisms that will commit us to much larger and faster increases in global temperatures than the basic projections suggest. Potential feedbacks include changes to processes such as ocean chemistry, massive release of methane from the arctic, and melting of the Greenland and/or Antarctic ice sheets (Meehl et al. 2007). If those thresholds are crossed, the ability of ecosystems and species (including our own) to adapt will be severely limited (Parry et al. 2007).

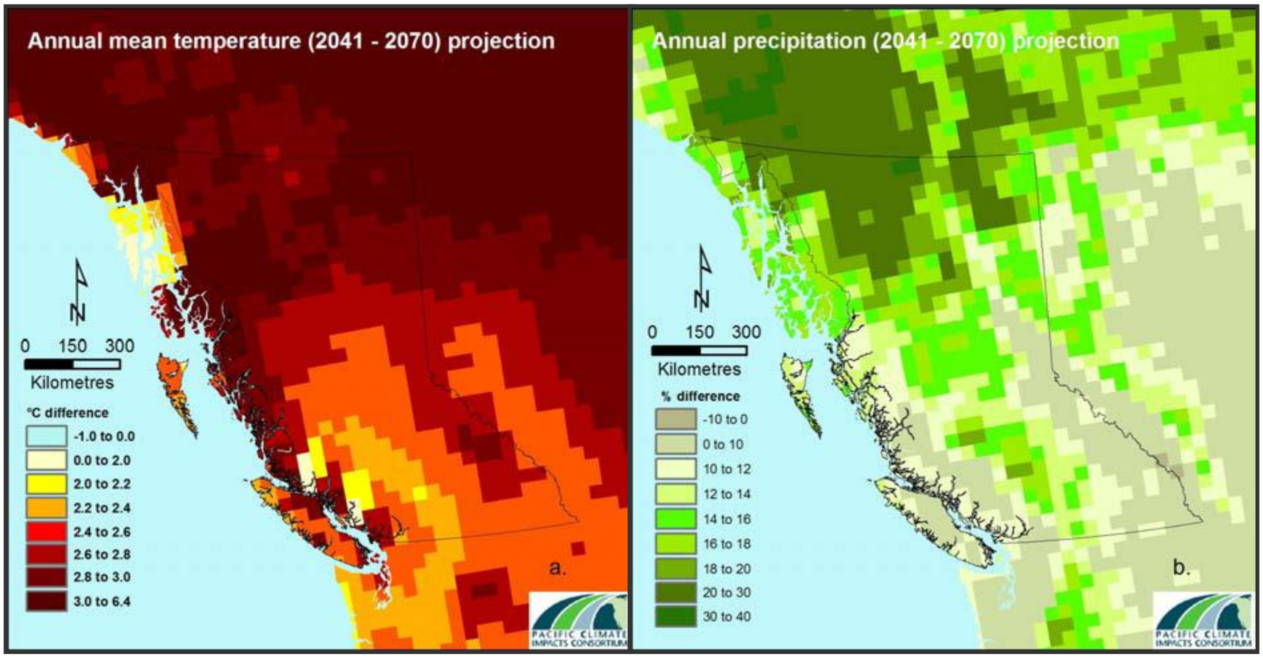


Figure A2. Climate change projections for the 2050s (averaged 2041-2070 *vs.* mean 1961-1990 baseline) from the Canadian Regional Climate Model (CRCM4 – resolution 45km) forced with Canadian Global Climate Model (CGCM3 – resolution approx. 350km) and A2 emissions scenario (a) annual mean temperature, and (b) annual precipitation (Rodenhuis 2007).

A1.4 Extreme Futures

It is generally accepted that if global mean temperature increases exceed 2^{O}C for a significant period of time, there is significant risk of runaway climate change due to the triggering of significant natural feedback mechanisms (Schneider et al. 2007). Exceeding that limit is likely to create conditions where adaptation will be of limited utility. As stated in the fourth IPCC report (Parry et al. 2007, p73):

> *Global mean temperature changes of 2 to 4°C above 1990- 2000 levels would result in an increasing number of key impacts at all scales (**high confidence**), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (**high confidence**) and West Antarctic (**medium confidence**) ice sheets.*
>
> *Global mean temperature changes greater than 4°C above 1990-2000 levels would lead to major increases in vulnerability (**very high confidence**), exceeding the adaptive capacity of many systems (**very high confidence**).*

Some recent assessments indicate we may already be committed to temperature increases beyond 2^{o}C (Canadell 2007, Ramanathan and Feng 2008), or at least have reached atmospheric greenhouse gas levels that will cause long-term changes to global systems (Solomon et al. 2009).

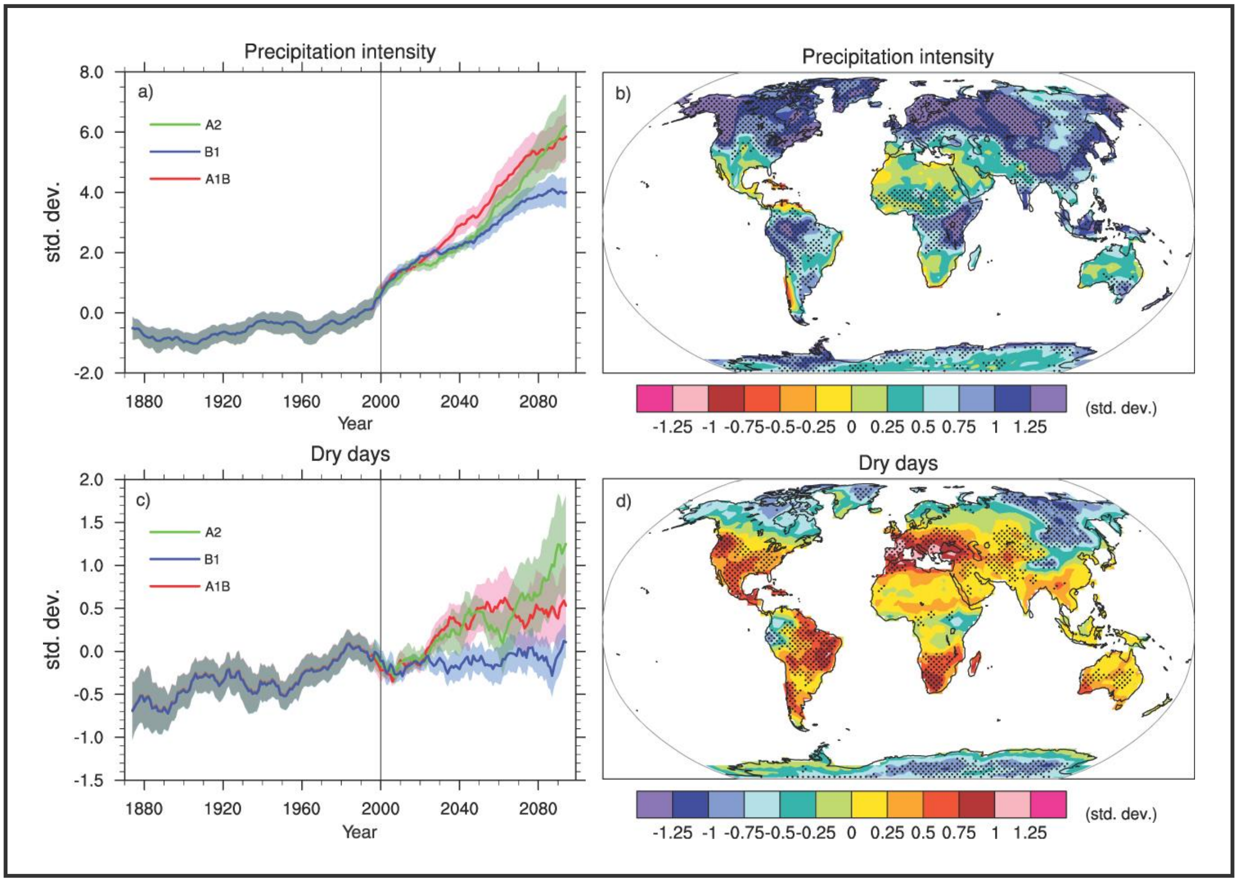


Figure A3. Illustrations of the predicted global increases in extreme weather events. Changes in extremes based on nine model simulations. (a) Globally averaged changes in precipitation intensity (defined as the annual total precipitation divided by the number of wet days) for three scenarios (see above). (b) Changes in spatial patterns of simulated precipitation intensity. (c) Globally averaged changes in dry days (defined as the annual maximum number of consecutive dry days). (d) Changes in spatial patterns of simulated dry days. Both (c) and (d) represent changes between two 20-year means (2080–2099 minus 1980–1999) for the A1B scenario. Solid lines in (a) and (c) are the 10-year smoothed multi-model ensemble means; the envelope indicates the ensemble mean standard deviation. Stippling in (b) and (d) denotes areas where at least five of the nine models concur in determining that the change is statistically significant. Each model's time series was centred on its 1980 to 1999 average and normalized (rescaled) by its standard deviation computed (after de-trending) over the period 1960 to 2099. The models were then aggregated into an ensemble average, both at the global and at the grid-box level. Thus, changes are given in units of standard deviations (from Meehl et al. 2007, p.785).

A1.5 Climate, Ecosystems and Human Society

The relationship between climate, forest and range ecosystems and human society is complex. The myriad of linkages between climate, ecosystems and society offer a wide variety of pathways for interactions and feedback. Figure A4 provides a generalized framework for examining some of those linkages in the context of forest and range ecosystems in British Columbia.

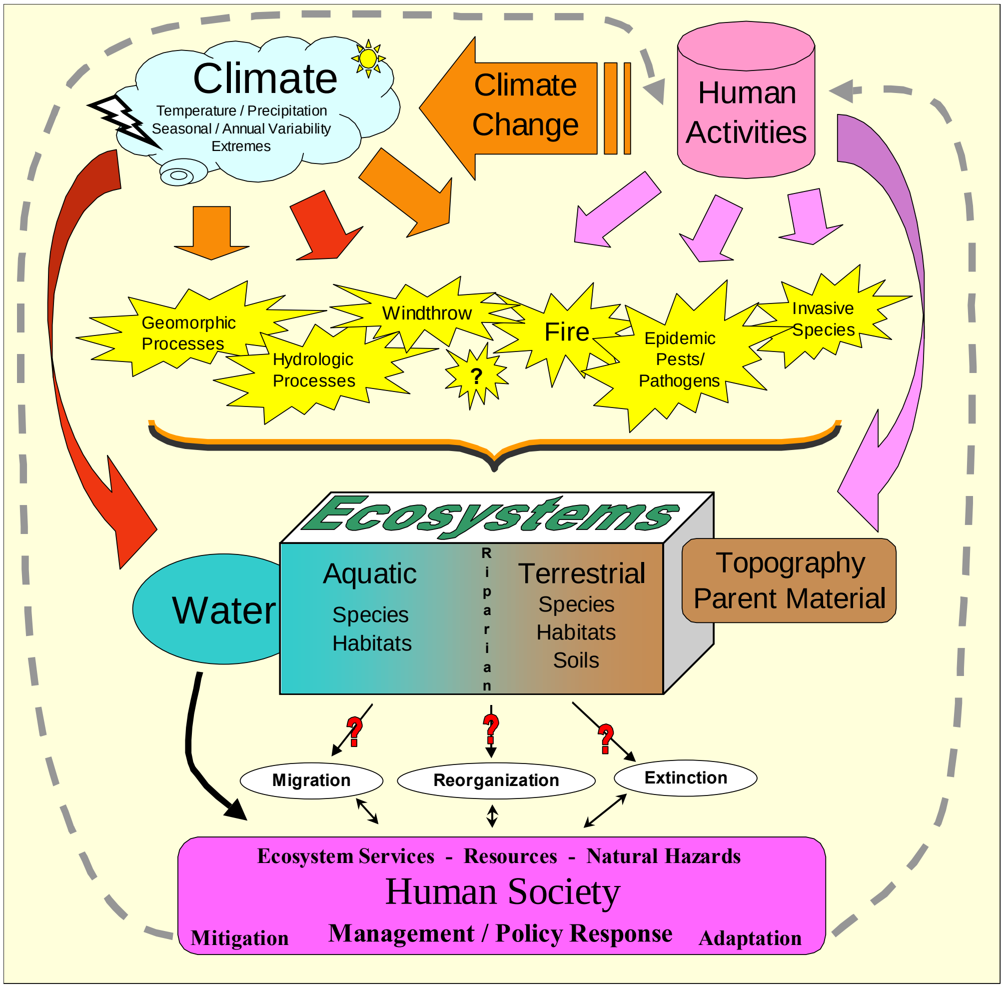


Figure A4. A schematic representation of the context and framework for a BC vulnerability assessment focused on forest and range ecosystems.

As climate change develops, it has direct and indirect impacts on both abiotic and biotic components of forest and range ecosystems and socio-economic aspects of human society (as shown in Figure A4). Climate change impacts are in addition to alterations to forest and range ecosystems brought about by other human activities (including forest and range management). In addition, climate change impacts are also distributed, amplified and/or offset through interactions with various disturbance mechanisms (e.g., windthrow, fire), and the processes that create linkages between the components of ecosystems and society (e.g., hydrologic regimes, decomposition). Ecosystems, ecosystem components and ecosystem processes will all change in response to climate change. Ecosystems themselves may adapt in a variety of ways (e.g., migration, reorganization, extinction). How they change and adapt will affect human society through changes in the provision of resources and ecosystem services and through changes in the magnitude and frequency of natural hazards. Human societyꞌs response to climate change, through adaptation and/or mitigation, will provide feedback to the overall system, and may either slow the changes or multiply them (see also Figure A4).

Historically, forest and range management have focused on maximizing the provision of forest and range resources for human consumption, while maintaining ecosystem services and managing risks of associated natural hazards (FSP-BCFs 2008, Kimmins 1996, Holling and Meffe 1996). Our past forest and range management activities (as well as other human activities) have already had significant impacts on forest and range ecosystems, and our ongoing management will continue to further influence them (Austin et al. 2008; Pimm 2007; Holt et al. 2003; Millenium Ecosystem Assessment 2000). In some cases our activities have been directed at, or had unintended impacts on ecosystem process and disturbance mechanisms as well (e.g., fire management, introduction of invasive spp., water quality degradation). Climate change impacts will be developing in an environment where there is already significant ongoing ecosystem manipulation and disruption (.

The focus of this report is on the impact of climate change on forest and range ecosystems; however, the existing cumulative and on-going stressors associated with other development activities will influence the ability of ecosystems to adapt and respond to climate change itself (Hansen et al. 2003, Warren et al. 2001). Outside of global and local mitigation efforts, direct management of climate change is not possible, leaving on-going management of other stresses the primary adaptation driver.

APPENDIX 2: VULNERABILITY ASSESSMENTS AND RISK MANAGEMENT – CONCEPTS AND APPLICATION

A2.1 Vulnerability Assessment Approaches

The concept of Vulnerability Assessment has been applied in both the biophysical and socio-economic contexts, leading to a wide variety of approaches and differing use of terminology. In the context of climate change, the IPCC and other researchers have tried to provide a consistent framework to improve consistency and comparison between different assessments (Carter et al. 2007, Fussel and Klein 2007). Simultaneously there has been a growing recognition of the need for integrated assessments that can better account for the interactions between the biophysical and socio-economic aspects of a changing world (Carter et al. 2007).

As the IPCC reports have evolved so has the approach to climate change impact, adaptation and vulnerability assessment. This evolution has primarily been in response to the growing need for policy-relevant information. Increasingly assessments have included assessment of adaptive capacity, social vulnerability, multiple stresses and adaptation in the context of sustainable development (Carter et al. 2007). Four main approaches to assessment have been dominant: impact assessment, vulnerability assessments, adaptation assessments, and integrated assessments. More recently a risk management approach has been introduced.

Impact assessments ï step1 in the development of a more comprehensive assessment - have focused on estimating the potential impacts and risks associated with climate change. Vulnerability assessments go beyond impact assessment by focusing on the vulnerabilities of the assessment targets, be they communities, regions or biophysical features. Adaptation assessments (see Figure A5) consider not only the potential impacts and vulnerabilities of the assessment target, but also the adaptive capacity of the target. Integrated assessments consider not only direct responses to climate change, but also consider interactions and feedbacks between multiple drivers and impacts, and will often link information across multiple scales and domains (e.g., biophysical, social and economic). Impact assessments are often completed by external bodies, while vulnerability, adaptation and especially integrated assessments, often include significant stakeholder participation (Fussel and Klein 2008 and Carter et al. 2007).

As the uncertainties around climate change predictions are combined with the potential gravity of the outcomes, the use of risk management approaches are becoming more common (Carter et al. 2007).

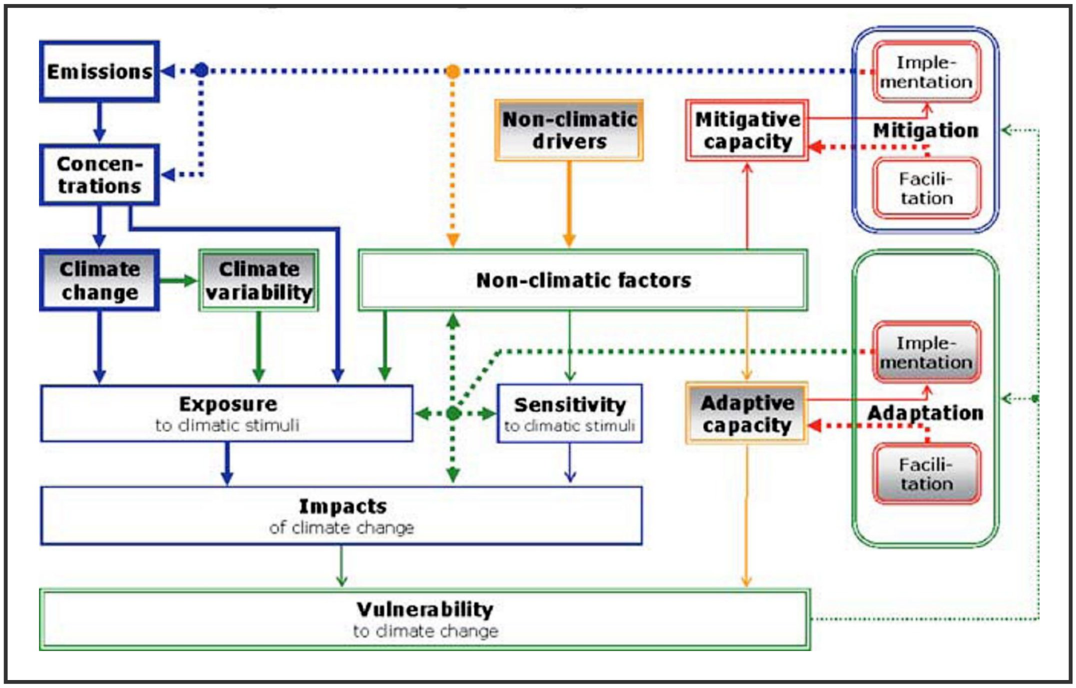


Figure A5. Conceptual framework for an adaptation assessment (from Fusel and Klein 2007, p.322).

Preston (2006) provides a simple example of a risk assessment approach for assessing the vulnerability of cold-water fish species in the U.S., demonstrating how uncertainty can be incorporated into decision-making. Preston compared the potential benefits of three CO_2 emission stabilization scenarios (350/550/750ppm CO_2, somewhat similar to scenarios in Figure A1). To incorporate uncertainty regarding the correlation of climate change and species response, he calculated probability functions for crossing various habitat/temperature thresholds based on existing regression models. He also used multiple climate models and multiple scenarios to incorporate uncertainty around climate sensitivity to CO_2 emissions. The results show that with no mitigation, the estimate of median percentage (and 95% confidence limits) of lost habitat would be 20-21% (12-30%), at 2025, 32-36% (20-58%), and 48-51%(20-100%) at 2100. As expected, capping emissions had little impact on 2025 impacts, but at 2050, 350/550/750 caps were predicted to reduce habitat loss by 30%/20%/20% respectively, and at 2100 by 50%/25%/15%. Reductions at the 95% confidence level were even more dramatic with reductions of 65%/40%/30%.

A2.2 Ecological Impacts and Vulnerabilities

Climate change **impacts** are defined by the IPCC as the "consequences of climate change on natural and human systems". ***Potential impacts*** – include all potential impacts that a projected change in climate may have, assuming no adaptations occur. ***Residual impacts*** include the impacts assessed after adaptation has occurred (IPCC glossary 2007a). As outlined above, we are focusing here on potential impacts to forest and range ecosystems, ecosystem components and processes.

'Vulnerabilities' are a more focused way to predict where impacts of significance may occur. Vulnerability is a summation of the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change (including variability and extremes). Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, the sensitivity of the system and its adaptive capacity (Parry et al. 2007, glossary).

An impact assessment is interested in observing impacts that have occurred to date. This provides a foundation from which to look forward. However, in order to predict potential future impacts it also needs to consider potential exposure to climate change and system óvulnerabilitiesô This allows some confusion of terms between assessing óvulnerabilitiesô and undertaking a full Vulnerability Assessment (see above). In this document we attempt to predict some potential impacts on ecological components by considering the vulnerabilities of different biophysical systems.

Components of ecosystems will be impacted directly by the change in climate itself (ñIts too hot or dry here, I can no longer live here), or indirectly (ómy alpine habitat is starting to become treed, I can no longer live here). Predicting indirect impacts is immensely complex and will include many unpredictable changes as individual elements within communities shift, causing knock-on changes elsewhere within the community. It has been suggested that although climate zones themselves will shift, there is no evidence to assume either that the ónew climateô will be anything observed previously in BC or elsewhere; new combinations of temperature, precipitation and their annual timings are likely to occur making future ecosystem forecasts extremely difficult (Williams and Jackson 2007).

A2.2.1 What are we assessing?

The focus of this assessment is limited to broad scale overview of climate change impacts to forest and range ecosystems, selected ecosystem components and critical ecosystem processes. It is not assessing related social, cultural and economic interests, nor is it providing a detailed evaluation of adaptive capacity. Although climate change will have impacts at all scales, this overview is generally limited to describing impacts at the landscape and watershed levels and above, with selected examples drawn from finer scales.

Climate change will impact individual components of ecosystems differently, and at various scales. Genes, species, and communities will all be individually affected, depending on their degree of exposure and their individual vulnerabilities and thresholds (see Figure A6). The cumulative impacts on whole ecosystems will therefore also differ depending on the scale at which they being assessed . While some ecosystems may be able to shift through space, most are expected to disassemble and reassemble in new forms, losing some species and elements and gaining others (Hobbs et al. 2006; Williams and Jackson 2007). Tracking impacts on ecosystems themselves is therefore difficult, because many ecosystems are not expected to continue intact into the future.

A quite different picture of impacts of whether something is vulnerable may be gathered when looking at a particular species within an ecosystem, compared with a site series or a whole region. As an example, a climate envelope may predict complete loss of an ecosystem from the southern part of the province, making it highly óvulnerableô Yet at a provincial or larger scale the same system may be expanding ï so is that ecosystem vulnerable, or not? Similarly, but at a different scale, it has been predicted that ponderosa pine may disappear from the PP BEC zone (Nitschke and Innes 2008), but may expand into other zones ï is that element or that BEC zone vulnerable?

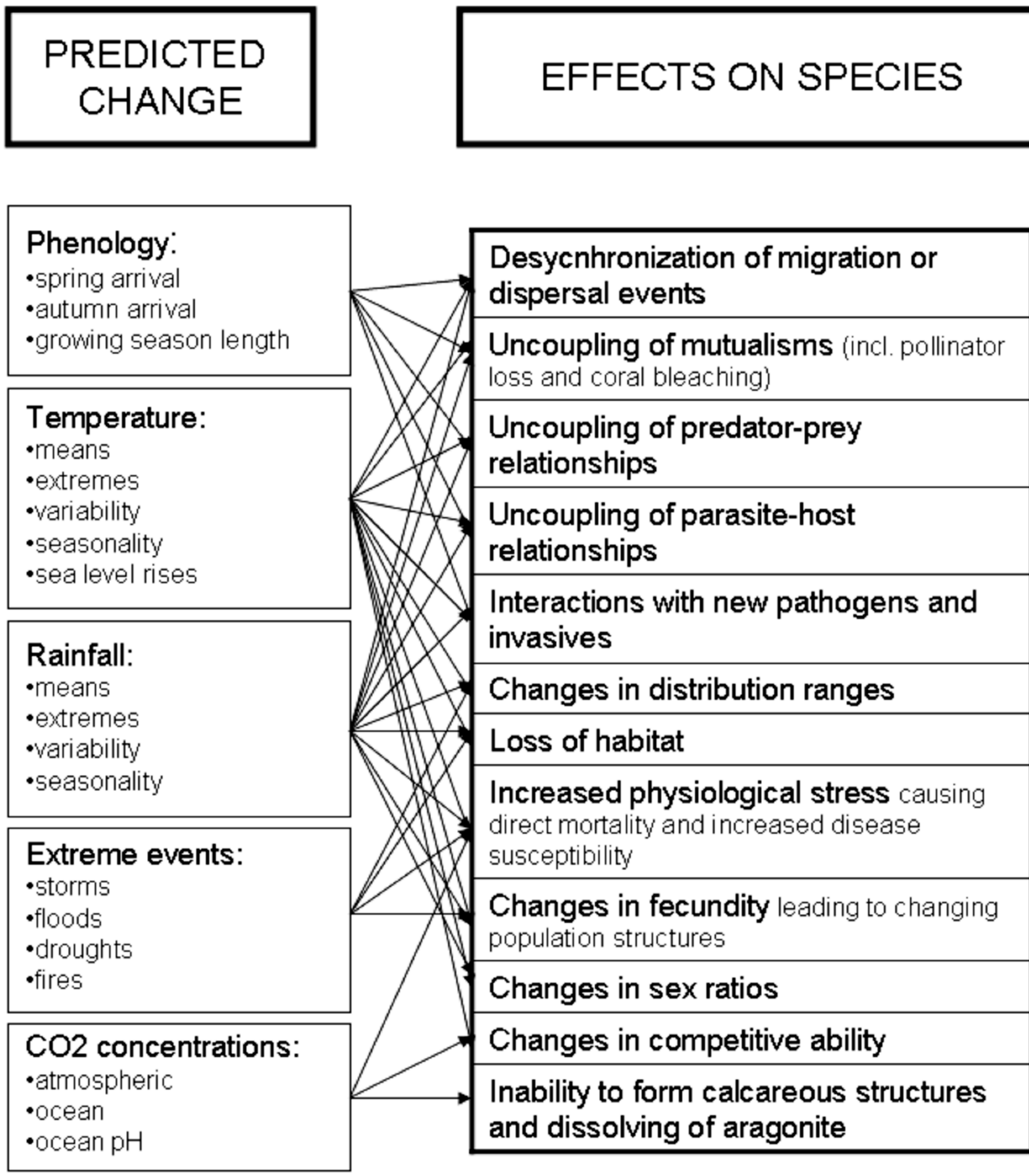


Figure A6. The complexity of impacts at the species level (from Foden et al. 2008, p.1).

The organisational scale at which impacts are assessed is therefore key ï the result will vary depending on the particular unit being considered. Given our poor understanding of how interactions may occur between elements and at different scales, this summary looks at impacts within a cross-cutting type of framework ï considering individual elements separately, and within the context of their ecosystems. Potential impacts are therefore organised into separate summaries, by process, ecosystems and ecosystem components (habitats and species). In addition, because different regions of the province are expected to incur differing impacts, we also roll-up some of the highest level types of impacts and their cascading effects by four broad regions of the province: Southern Interior; Central Interior, Northern Interior and Coastal (see Appendix 3 for a map and descriptions of region locations).

A2.2.2 When are impacts significant?

In early IPCC reports, panels of scientists produced extensive lists of the impacts that had occurred already, and those that were predicted to occur under different climate scenarios. Paralysis from information overload ensued, and future IPCC reports focus on identifying **critical impacts** – i.e. impacts that are significant enough that they should be avoided at any reasonable cost (Martin Parry Section 3.7 in IPCC Expert Meeting on Key Vulnerabilities May 2004)[8].

Clearly, defining 'critical' or 'significant' is partly related to the scale being considered. Global, provincial, regional and local significance will all differ from each other, and a full suite of adaptation strategies will require consideration of all scales. The following list from the IPCC provides factors to consider when looking to identify the most critical impacts of biophysical systems: (Schneider et al. 2007, pp.785-786):

Magnitude / Extent of Impacts: these are an indication of the degree of ecological change – are there complete changes in ecosystem structure and function, or are there only changes in species frequency? The degree of change can be measured in absolute terms or relative to the natural variability experienced in a system historically (Compass 2008). This latter definition may prove most useful to identify critical vulnerabilities for biophysical systems. Rate of change is also important – high rates of change reduce opportunities for adaptation and therefore have a higher probability of resulting in significant impacts.

Timing of Impacts: if the impact is expected to occur sooner, rather than later, then its significance is likely to be greater. However, impacts that manifest in the long term, but are the culmination of processes that are initiated in the short term may also be critical. An example of a longer term impact that may be key would be melting of glaciers and their downstream effects.

Reversibility or Persistence: changes that cannot be reversed are likely to be more critical than those that are reversible. Such changes would include extinction of species, declines of functionally important species, shifts in natural disturbance regimes that push ecosystems into alternate states.

Thresholds: Ecological thresholds – *points at which the rate of change increases* – are important because they a) can occur with no warning, so reducing the chance for adaptation, and b) because they often define a 'tipping point' beyond which it can be extremely difficult to return to previous conditions. Ecological thresholds can be identified in a number of different ways – when, for example, a species has a relatively narrow niche limit beyond which it cannot exist in a particular locale – for example cold water fish species and stream temperature. Even small changes that push temperatures out of that narrow zone may result in large areas being suddenly unsuitable for a particular fish species. The concept of thresholds can also be applied at different scales, such as the population scale – when sufficient habitat becomes unsuitable, the population may no longer be able to persist within a particular region due to metapopulation dynamics that lower reproductive success (Pulliam 1998). Such examples may occur for increasingly isolated populations such as those associated with alpine environments today. There is much difficulty incorporating the possibility of extreme, or abrupt 'tipping' points in any analysis of regional impacts. These events by their nature are difficult to predict and likely give little warning of their imminent arrival.

Functional Value: the functional importance of a particular element, species or ecosystem will have direct implications to the scope of cascading impacts flowing out from a particular impact. Loss of

---

[8] This links to the United Nations Objective Framework on Climate Change whose broad purpose is to avoid **'dangerous levels' of climate change**', which are intended to be achieved in a timeframe so as to: a) allow ecosystems to adapt naturally to climate change; b) to ensure that food production is not threatened; c) to enable economic development to proceed in a sustainable manner.

keystone habitat such as snags, or a keystone species such as woodpeckers, could have cascading effects through increasing populations of insect prey species and potentially allowing insect outbreaks. Alternatively, significant change to foundation species or processes (high functional importance) may also have critical impacts. Strongly-interacting species would have a similar influence. For example, loss of predators can cause massive response from prey species, and to associated forage species (e.g. Ripple et al. 2003). Changes to natural disturbance dynamics may also fundamentally alter ecosystem structure (e.g., forest to grassland), with massive scales of cascading impacts.

Potential for Adaptation[9]: focusing on ecological impacts and vulnerabilities, we are interested in whether ecosystem components will be able to ‘adapt’, ‘move’ or ‘evolve’ in order to maintain themselves on the landbase. One of the greatest concerns regarding biodiversity is loss of species or functions, and simplification of ecosystems which is predicted to result in increasing vulnerability to future disturbance (invasive species, insect outbreaks etc.). Characteristics such as environmental amplitude, genetic variability and seed dispersal would be important for individual species, while functional redundancy will be important for ecosystems.

In Summary: the combination of factors listed above provide direction on which sorts of considerations can be used to determine where critical impacts are most likely to occur. In addition to identifying broad vulnerabilities, it is also important to identify climatic thresholds that may result in critical, irreversible impacts on a system as these can also be used to information adaptation strategies (Jones 2001).

A2.2.3 Uncertainties and Risks

The uncertainties associated with assessing potential future impacts of climate arise from a number of areas. They include:

- **uncertainty around climate change itself**. In addition to the discussions above regarding uncertainties about GHG emissions and the rate and magnitude of global climate change, there is additional uncertainty regarding how climate variables such as temperature, precipitation, winds, seasonality, and the frequency and magnitude of extreme events will be distributed across the landscape at a local level. The resolution of present climate models is improving (Le Treut et al. 2007, Rodenhuis 2008), but it has not yet reached a scale appropriate for detailed ecosystem assessments.
- **linkages between climate change and individual impacts**. Individual species with known autecologies (e.g., specific temperature limits for coldwater fish species survival) provide opportunities for relatively certain predictions for change. Many other species have unknown autecologies – the fundamental niche (where it is possible to live) may differ greatly from the realized niche (where it lives today). For these (the vast majority) of species, climate impacts are difficult to predict (see Figure A6). Moving up to the next level – the biophysical world is comprised of much more complex systems – species interacting with each other to create communities that interact with the abiotic world to create ecosystems. The uncertainty associated with how these interactions will change is also large. Finally, ecological systems are molded by natural disturbance processes that again are expected to shift. There are obvious uncertainties that can become compounded at each of these stages.
- **interactions with cumulative impacts of past human activities** and other stresses (Schneider et al. 2007, Warren at al. 2001). It is often difficult to partition impacts of particular changes (e.g., increased stream temperature – how much results from riparian harvesting, how much from climate change?). In other cases climate change and past human activities will interact to create the impacts (e.g., fire control allowing a build-up of forest fuels, and climate change creating a longer fire season, drought and high summer temperatures).

[9] Within IPCC reports, adaptation potential is often focused on human systems. It is extremely difficult to define or measure for many ecological systems.

- **rate of climate change**. The IPCC states that faster changes will exacerbate impacts because species will be unable to adapt or move at the same rate as climate will change. Studies suggest significant impacts are already unavoidable: a summary for terrestrial species suggests 15 ï 37% of species may be committed to extinction by 2050 due to existing change (Thomas et al. 2004; Parmesan 2006), and similar effects are expected in some aquatic systems (e.g., Carpenter et al. 2008).
- **unknown unknkowns**. With climate change creating conditions that have never existed in the span of human experience, there will undoubtedly be new interactions and occurrences that have no known corollary.

The IPCC (2007a) uses a two tiered description of uncertainty to help focus their discussion. **Likelihood** is the probability that an outcome will occur in the future and **confidence** is a subjective assessment that any statement about an outcome will prove correct (i.e. it defines the óspreadô around the likelihood). Similar magnitude of impacts, but which vary in likelihood and confidence are more likely to be considered key if it is more certain that they will occur. However, conversely, this doesnõt mean that unlikely or low confidence outcomes may not ultimately have critical impacts.

APPENDIX 3: REGIONAL BOUNDARIES

Given the uncertainties around how climate impacts will play out, the exact boundaries of these regions are not intended to be specific. In general terms however:

- Northern Interior: areas east of the height of land of the coast mountains, including the northern plateaus and mountains (generally the Northern Boreal Mountains, Taiga Plains and Boreal Plains Ecoprovinces),
- Central Interior: the largely plateau country in the central portion of the province, generally including the Sub-boreal Interior and Central Interior Ecoprovinces
- Southern Interior: the southern interior, generally including the Southern Interior and Southern Interior Mountains Ecoprovinces
- Coast: the BC coast, generally including the Georgia Depression and the Coast and Mountains Ecoprovinces

The regions are generally identified on the map shown in Figure A7.

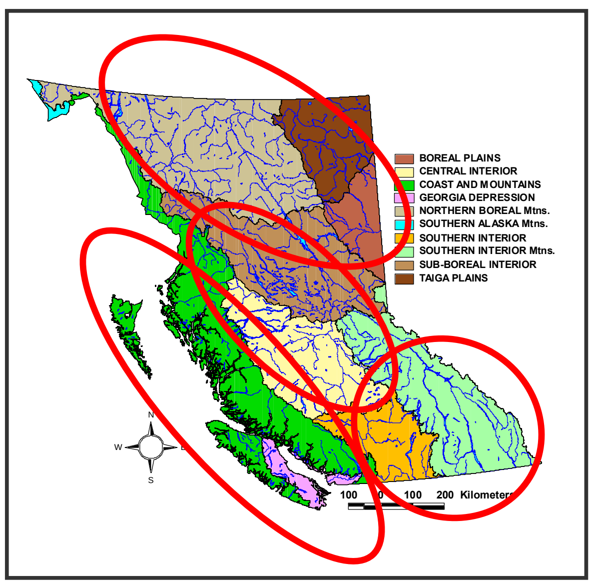


Figure A7. Generalized regions used in the regional descriptions of climate change impacts overlaid with the Ecoprovinces of BC.