BRITISH COLUMBIA

# CHAPTER 8
# British Columbia

**Lead authors:**
Ian J. Walker[1] and Robin Sydneysmith[2]

**Contributing authors:**
Diana Allen (*Simon Fraser University*), Karin Bodtker (*Parks Canada*), Derek Bonin (*Greater Vancouver Regional District*), Barry Bonsal (*Environment Canada*), Allan Carroll (*Natural Resources Canada*), Stewart Cohen (*Environment Canada*), Audrey Dallimore (*Natural Resources Canada*), Holly Dolan (*Agriculture and Agri-Food Canada*), Ze'ev Gedalof (*University of Guelph*), Allison Gill (*Simon Fraser University*), Richard Hebda (*Royal British Columbia Museum*), Robert Hicks (*British Columbia Water and Waste Association*), Phillip Hill (*Natural Resources Canada*), Kim Hyatt (*Fisheries and Oceans Canada*), Ralph Matthews (*University of British Columbia*), Brian Menounos (*University of Northern British Columbia*), Trevor Murdock (*Pacific Climate Impact Consortium*), Denise Neilsen (*Agriculture and Agri-Food Canada*), Rosemary Ommer (*University of Victoria*), Andrew Pape-Salmon (*BC Hydro*), Marlow Pellatt (*Parks Canada*), Daniel Peters (*University of Victoria*), Terry Prowse (*University of Victoria*), Dave Spittlehouse (*British Columbia Ministry of Forests*), Stephen Sheppard (*University of British Columbia*), Bill Taylor (*Environment Canada*), Arelia Werner (*University of Victoria*), Paul Whitfield (*Environment Canada*), Tim Williamson (*Natural Resources Canada*), Johanna Wolf (*Tyndall Centre for Climate Change Research*), Monika Winn (*University of Victoria*)

Recommended Citation:

Walker, I.J. and Sydneysmith, R. (2008): British Columbia; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 329-386.

---

[1] Department of Geography, University of Victoria, Victoria, BC

[2] Department of Sociology, University of British Columbia, Vancouver, BC

# CONTENTS

# KEY FINDINGS

Climate change is increasingly affecting British Columbia's landscapes, communities and economic activities. Future projections show that climate change will continue and suggest that direct and indirect impacts will become more pervasive. The following are some of the key risks and adaptation opportunities associated with climate change in BC:

**Many regions and sectors of British Columbia will experience increasing water shortages.** Smaller glaciers, declining snowpack, shifts in timing and amount of precipitation, and prolonged drought will increasingly limit water supply during periods of peak demand. Competition amongst water uses will increase and have implications for transborder agreements. Ongoing adaptive measures include the incorporation of climate change impacts into some official water management plans, upgrades to reservoir capacity and various demand management initiatives.

Hydroelectric power generation, especially during (increasing) peak energy demands in summer, is particularly vulnerable to climate change. Hydroelectricity currently accounts for nearly 90% of BC's power supply. Adaptation will involve managing electricity demands, which are expected to increase by 30 to 60% by 2025, and updating power-generating infrastructure, both of which are already part of current planning and management measures. Small hydro and 'run of river' alternatives can increase capacity but are more vulnerable to variable river flows than are facilities with large storage reservoirs. Alternative 'clean' sources of energy, such as wind power, will help meet increasing energy demands in the future, but are currently only a small contributor to BC's power supply. Coal-fired generating plants are also being considered, although their status is uncertain as they must now meet strict new zero net emissions targets established by the recently released BC Energy Plan.

**Increasing frequency and intensity of extreme weather and related natural hazards will impact British Columbia's critical infrastructure.** Windstorms, forest fires, storm surges, coastal erosion, landslides, snowstorms, hail, droughts and floods currently have major economic impacts on BC's communities, industries and environments. In low-lying coastal areas, certain risks will be magnified by sea-level rise and increasing storminess. The costs associated with managing and reducing impacts of extreme events are rising. British Columbia's transportation network, port facilities, electricity and communications distribution infrastructure are major investments where replacements or upgrades present adaptation opportunities for incorporation of revised hazards assessments that consider changing climate conditions and sea-level rise. Integrated stormwater management, an approach adopted by the Greater Vancouver Regional District, aims to manage stormwater run-off to protect urban stream health and includes consideration of climate change impacts. Integrating climate change and sea-level rise into infrastructure planning improves risk and life-cycle cost management, and will reduce the vulnerability of BC's critical infrastructure.

**British Columbia's forests, forest industry and forestry-dependent communities are vulnerable to increasing climate-related risks, including pest infestations and forest fires.** As of 2007, the mountain pine beetle outbreak affected approximately 9.2 million ha of BC's forests. The severity and longevity of this outbreak are linked to past management practices (e.g. fire suppression) and climate change. Major hydrological and ecological changes are expected in pine-dominated watersheds as a result of tree mortality and massive increases in logging activity to salvage beetle-killed timber. Initial economic gains will be substantial, but may give way to longer term social and economic instability without careful planning. Increasing international competition in the forestry sector will result in additional future challenges. The Future Forests Ecosystem Initiative of the BC Ministry of Forests and Range represents an early step toward long-term forest management planning that considers climate change in conjunction with other pressures.

**Climate change will exacerbate existing stresses on British Columbia's fisheries.** Future impacts include invasion of coastal waters by exotic species, rising ocean and freshwater temperatures, and changes in the amount, timing and temperature of river flows. Freshwater fisheries may experience increased water management conflicts with other uses (e.g. hydroelectric power generation, irrigation, drinking water), particularly in the southern interior. The vulnerability of Pacific salmon fisheries in both freshwater and saltwater environments is heightened by the unique social, economic and ecological significance of these species. Aquaculture, an increasingly important element of economic development on the coast, has potential to enhance food security while lessening the stresses on wild fisheries. However, the cultural and ecological impacts of aquaculture, and salmon farming in particular, are controversial.

**British Columbia's agricultural sector faces both positive and negative impacts from climate change.** Changes in precipitation and water supply, more frequent and sustained droughts, and increased demand for water will strain the adaptive capacity of most forms of agriculture. Growing conditions may improve in some regions or for some crops, although the ability to expand agricultural regions will be constrained by soil suitability and water availability. Increasing demand for irrigation will have to compete with other water uses, especially in areas of high growth.

**Integrating climate change adaptation into decision-making is an opportunity to enhance resilience and reduce the long-term costs and impacts of climate change.** Currently, this happens indirectly in larger urban centres, where sustainable building practices and demand management of water and energy arise from efforts to enhance sustainability and reduce greenhouse gas emissions. Drought-prone regions, such as the Okanagan region and the Victoria Capital Regional District, have aggressive restrictions on watering and rebates for high-efficiency consumer product replacements that have both adaptation and mitigation benefits for climate change. In remote coastal and rural communities, resilience arises from experience and exposure to the impacts of extreme weather on critical infrastructure (e.g. coastal highways, ferries, air service, power generation and communication) and on natural resources (e.g. fisheries and forests). Social networks, volunteerism, income diversification and food stockpiling also contribute to adaptive capacity and enhance resilience.

# 1 INTRODUCTION

## 1.1 ORGANIZATION OF THIS CHAPTER

This chapter provides an overview of climate change impacts and adaptation issues in British Columbia, with an emphasis on recent and ongoing work leading to adaptation action. The impacts of, and adaptation to, climate change in British Columbia will vary across the province's diverse landscapes, communities and socioeconomic activities. Available information covers the breadth of issues unevenly, with research being abundant on some topics (e.g. water resources and fisheries) and very limited for others (e.g. energy and transportation). Available information also focuses strongly on the impacts of climate change, although adaptation is becoming a more significant element of recent studies.

This introduction provides a broad overview of BC's physical and human landscapes, and briefly summarizes some key adaptation challenges in different regions of the province. Section 2 discusses drivers of climate variability in BC, and examines historical trends and future projections of major biophysical indicators of climate change. In Section 3, the implications of these biophysical changes are discussed in the context of adaptation to multiple stressors within key economic sectors. Greater detail on selected regional issues is presented in Section 4 as integrated case studies, highlighting the general trend from impacts research towards adaptation action. The concluding section of the chapter presents a synthesis of common themes, key insights and lessons learned from materials presented in the preceding sections.

## 1.2 CLIMATE AND PHYSICAL GEOGRAPHY

British Columbia is the most physically and biologically diverse region in Canada. The proximity of the Pacific Ocean and presence of several major mountain chains significantly influence BC's climate and ecosystems (Valentine et al., 1978). On the coast, mild, moist Pacific air encounters the steep Coast Mountains to produce a humid, maritime climate with annual air temperatures above 5°C and total annual precipitation exceeding 1000 mm (Figures 1 and 2). Some of the warmest climates in Canada occur in BC's southern coast and interior regions. The south-central BC coast has a warmer and drier climate in the rain shadow of Vancouver Island. The driest and warmest climates of BC (semiarid steppe) occur in the rain shadows of the Coast and Cascade ranges, and in the valleys of the southern interior west of the Columbia Mountains.

A humid continental climate predominates in central and southeastern BC. The Rocky Mountains restrict westward flow of cold Arctic air from the Prairies, moderating winter climate in the region. The Interior Plateau underlies most of this area and is the main catchment area for the Fraser and Columbia rivers. The climate of northern BC is controlled by the influx of cold Arctic air, the intensity of the continental high-pressure system, and inflow of warm dry air in the summer. This produces subarctic and boreal climates with very cold winters and short mild summers. This region is a complex landscape of mountains and plateaus that grade northeastward into the Great Plains. Average annual precipitation is low (less than 500 mm) in the interior plains and valleys, increasing to greater than 1000 mm along the coast and in the mountains. Three major river systems, the Peace, Liard and Skeena rivers, occupy this landscape.

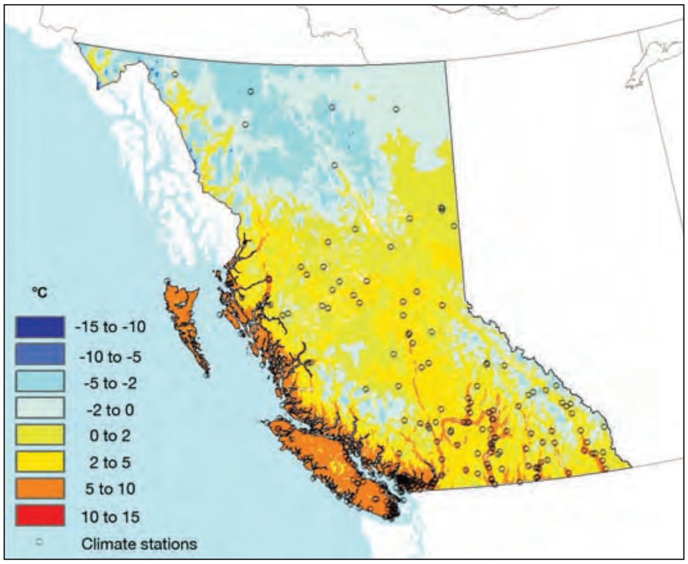


**FIGURE 1:** Annual mean temperature in British Columbia 1961-1990 PRISM[3] average. The PRISM numerical method interpolates station observations to a 4 km grid considering physical factors such as slope aspect and elevation . The PRISM model is considered more robust in areas with higher density of data collection stations and at elevations near the stations (Daly et al., 2002).

---

[3] Parameter-elevation Regressions on Independent Slopes Model, for more information *see* http://www.ocs.oregonstate.edu/prism/index.phtml [accessed May 18, 2007].

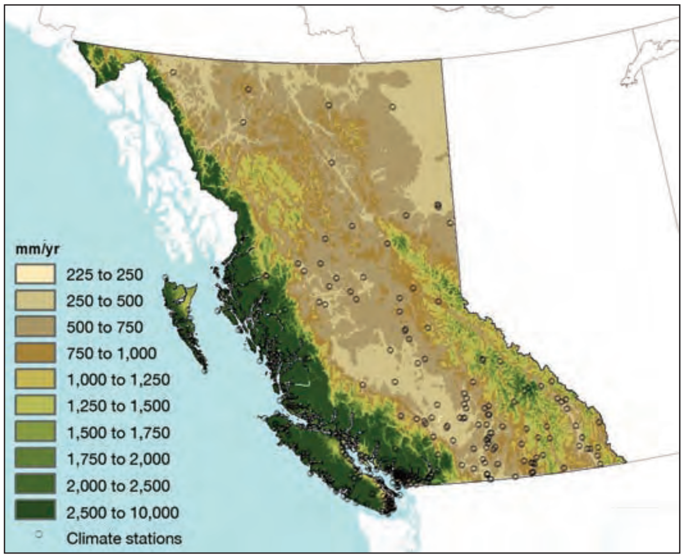


**FIGURE 2:** Annual total precipitation in British Columbia from 1961-1990 PRISM (*see* Figure 1) average. The wettest climates in Canada occur on BC's coast, especially on mountain slopes of Vancouver Island, the Queen Charlotte Islands and the mainland Coast Mountains.

Coastal British Columbia has a cool, moist, maritime climate influenced by the northeastern Pacific Ocean. In winter, midlatitude cyclonic storms move ashore and bring abundant precipitation to much of the coast. Variations in winter climate result from changing frequency and intensity of coastal storms. In part, this is due to the position of the prevailing storm track and the intensity of major low-pressure systems, such as the Aleutian Low. In summer, a subtropical high-pressure system moves northward in the northeastern Pacific, and storms are less frequent and approach the coast farther north. Variability in BC's climate is responsive to changes in the intensity of these oceanic pressure systems, which in turn are associated with changing ocean temperatures and currents. As such, variability in most of BC's climate is connected to large-scale ocean-atmospheric phenomena, namely the El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; *see* Section 2.1 and Chapter 2).

## 1.3 BIOGEOGRAPHY AND ECOLOGICAL DIVERSITY

British Columbia can be divided into 14 biogeoclimatic zones (Krajina, 1965; Pojar and Meidinger, 1991; Hebda, 1998), distinguished by climate, latitude, elevation and distance from the coast (Figure 3). This biogeoclimatic classification system is used widely for both planning and research purposes (e.g. Mitchell et al., 1989; Hamann and Wang, 2006). Biodiversity varies within and between zones, although there are generally more species in the south and/or at lower elevations. In some regions, such as mountainous areas of southern BC, as many as six biogeoclimatic zones supporting thousands of species can be encountered across distances of only a few kilometres.

Local disturbances, such as fire, insects, disease, windthrow and human activity, significantly influence species distributions. Some disturbances, such as mountain pine beetle outbreaks, are exacerbated by climate change (*see* Section 4.2). Ecosystem responses to future climate change will be localized and depend on both natural and anthropogenic factors, including species sensitivity, the severity of the climate change and features that inhibit or enable species migrations, such as urban sprawl and the presence of migration corridors.

## 1.4 HUMAN ENVIRONMENT

The ability of British Columbia's communities and economic sectors to respond and adapt to climate change will depend as much on social and economic characteristics as it will on location and climate. Eighty-five per cent of British Columbians live in urban areas, mainly within the regions of greater Vancouver and Victoria, but also in several 'regional hubs' that include Kelowna-Vernon, Kamloops, Prince George and Prince Rupert. Rural BC consists of many smaller towns and First Nations communities dispersed along the coast and in the interior. The social and cultural landscape of BC is changing in many ways in response to local and global economic shifts, urbanization trends, immigration and technology. Climate change will influence and affect these communities differently.

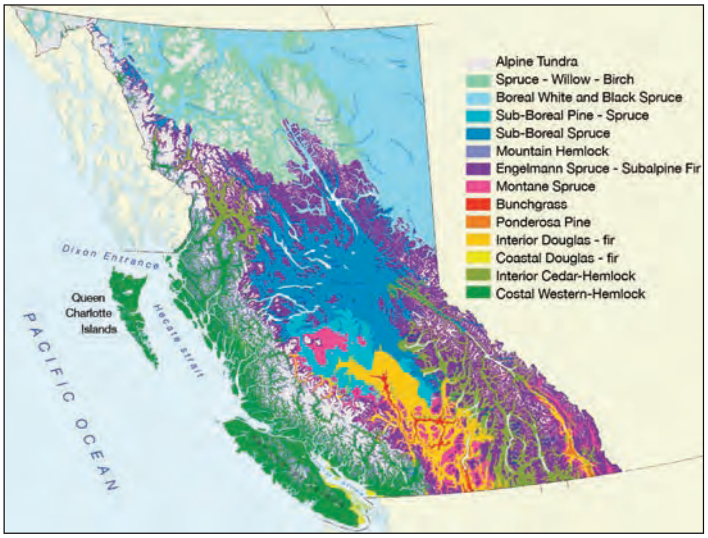


**FIGURE 3:** British Columbia's 14 biogeoclimatic zones (*after* Pojar and Meidinger, 1991).

The historical mainstay of BC's economy is the extraction, processing and export of natural resources, mainly wood, fish and minerals. Over the past 15 to 20 years, the contribution of natural resources to BC's economy, relative to total production and employment income, has declined in response to various environmental, social and economic changes (*see* Section 3). Traditional patterns of development and the relationship between major urban centres and rural regions are beginning to change in response to globalization and other factors (Matthews and Young, 2005). Despite this ongoing transformation, natural resources continue to dominate provincial exports and remain especially vital to the social and economic health of rural BC (Baxter and Ramlo, 2002; BC Ministry of Labour and Citizens' Services, 2004b).

Recent demographic trends in BC have been driven by urbanization and immigration. The province has the second highest immigrant population in Canada after Ontario (Statistics Canada, 2001). Population in 2005 was 4.25 million, and is projected to reach 5.6 million by 2031 (BC Ministry of Labour and Citizens' Services, 2005a; Statistics Canada, 2005). Growth is concentrated in the Greater Vancouver Regional District (+8.5%), the Okanagan region (+8.2%) and the Squamish-Lillooet Regional District (+12.3%)[4]. In contrast, some northern and coastal districts, such as northern Vancouver Island (–10.2%) and the Skeena–Queen Charlottes (–12.5%), have experienced recent population declines (Statistics Canada, 2001). In part, this reflects out-migration spurred by job losses in resource-dependent communities and the general economic downturn in remote and rural communities during the past 10 to 15 years (Marchak et al., 1999; Hayter, 2000; Baxter and Ramlo, 2002; Matthews, 2003; Hanlon and Halseth, 2005; Young, 2006a, b).

The historical tendency in BC for broad swings across the political spectrum between successive elections has had both positive and negative effects on adaptive capacity at the community scale. Restructuring of rural and resource development policy and the delivery of services to remote communities has led many communities to become 'entrepreneurial risk takers' (Young 2006a, b), and to assume a greater role in local resource management, community development and service delivery (Young, 2006a, b; Matthews and Young, 2007; Ommer, 2007). For small communities with limited adaptive capacity, dealing with such short-term issues limits their ability to simultaneously prepare for, and adapt to, a changing climate (Brenner and Theodore, 2002; Herbert-Cheshire and Higgins, 2004).

Another key factor that will affect future adaptation in British Columbia is the pending changes in jurisdiction and responsibility for future land- and resource-use management and planning that will occur as treaties are eventually signed between First Nations and the governments of Canada and BC[5]. These changes will have important, although as yet undetermined, implications for adaptation, especially in coastal and rural regions of the province.

## 1.5 REGIONAL CHALLENGES

The impacts of climate change and the approaches to adaptation will vary across British Columbia's disparate regions and economic sectors (*see* Section 3).

About 75% of BC's population lives in the Vancouver–Lower Mainland region, where both the population and the economy have greatly diversified in recent decades. The communications technology, entertainment (especially film production), light industry, greenhouse agriculture, biotechnology, construction, retail and service sectors have all become major elements of the regional economy, joining more established sectors such as tourism, transport and port functions (Vancouver Economic Development, 2006). Currently, the region is investing heavily in infrastructure for the 2010 Winter Olympics and to support continued growth and development over the next few decades. Managing growth within the objectives of the official 'Liveable Region Strategic Plan' (Greater Vancouver Regional District, 1999) will require consideration of, and planning for, climate change. The Victoria Capital Regional District (CRD), the political and administrative hub of the province, is also expected to see continuing population and economic growth. Current climate risks in both the Greater Vancouver Regional District (GVRD) and the CRD include water shortages associated with frequent droughts and the impacts of extreme weather events. These risks are expected to increase in the future, with significant implications for municipal infrastructure (*see* Section 4.4).

In northern and central BC, the current mountain pine beetle (MPB) outbreak exemplifies the linkages between climate change, natural pest cycles and resource management practices (*see* Sections 3.3 and 4.2). The initial response to the crisis was to increase harvest levels two to three times in an effort to secure the timber value of infected trees before they rot. The social and environmental consequences of both the outbreak and the response, although uncertain, are a concern for many interior communities. In areas most heavily infected, managing the current and anticipated impacts of the outbreak overshadows most other issues.

---

[4] Population growth projections and more detailed statistics and analysis are also available at <http://www.bcstats.gov.bc.ca/DATA/pop/popstart.asp> [accessed May 18, 2007].

[5] The BC Treaty Commission and Treaty Negotiation Process were established in 1992 to facilitate negotiation of "fair and durable treaties" (<http://www.bctreaty.net/files/publications.php> [accessed April 30, 2007]) between BC First Nations and the governments of British Columbia and Canada. Unlike the rest of Canada, most indigenous groups in BC never formally relinquished rights or title to their traditional territories (Tennant, 1990; Muckle, 1998). Aboriginal title was officially recognized by the courts in the 1990s (Delgamuukw v. British Columbia, [1997] 3 S.C.R. 1010).

Northeastern BC is currently experiencing an oil and gas resource boom, which started in the 1990s and peaked in 2003 (Canadian Association of Petroleum Producers, 2005, 2006). The strong regional economy attracts workers from areas of high unemployment around BC and across Canada. There has been little study of the impacts of climate change in this corner of the province, although adaptation challenges are likely to be similar to those in adjacent parts of Alberta (*see* Chapter 7).

Communities along the north-central coast of BC have experienced significant social and economic change in the past 10 to 20 years, with many communities experiencing significant unemployment, social stress and depopulation (Matthews, 2003; Ommer, 2006; Young, 2006a, b). Communities along the southern coasts have faced similar challenges, although they are ameliorated partly by proximity to the major economic centres of Vancouver and Victoria. The future of coastal communities in light of climate change and other stressors will depend on economic diversification and renewal; as such, adaptation will be closely linked to regional development. Potential areas for diversification include tourism, community forests and aquaculture (BC Ministry of Environment, 1997a; Matthews and Young, 2005). Although all have their limitations, salmon aquaculture faces additional challenges due to the politically and ecologically contentious nature of current practices (BC Ministry of Environment, 1997b; Gardner and Peterson, 2003; Naylor et al., 2003; Morton et al., 2005; Gerwing and McDaniels, 2006; *see* Section 3.2).

Southeastern BC encompasses two subregions, unified by the central role of water supply in land-use and resource management decisions. The Okanagan valley has strong orchard industries and more than 90% of BC's wineries and vineyards (Northcote, 1996; BC Ministry of Labour and Citizens' Services, 1997, 2005c; Bremmer and Bremmer, 2004). The region has experienced rapid growth and development in the past twenty years, and now supports an established tourism sector and burgeoning retirement population (McRae, 1997). The region's water resources are already stressed, and future shortages will be exacerbated by climate change (Cohen et al., 2003, 2006; *see* Section 4.3). To the east, the Columbia-Kootenay region hosts much of the province's hydroelectric generating capacity. Climate change impacts on snow pack and glaciers will limit the quantity and alter the timing of water availability for power generation in the region. These changes will excacerbate the existing challenges for water managers of reconciling competing demands of domestic, agricultural, fisheries, industry and commercial users, as well as meeting obligations to partners in interprovincial and international agreements (Volkman, 1997; Smith et al., 1998).

# 2 INDICATORS OF CLIMATE VARIABILITY AND CHANGE

## 2.1 UNDERSTANDING CLIMATE VARIABILITY

Two major ocean-atmosphere phenomena strongly influence climate variability in British Columbia: 1) the El Niño–Southern Oscillation (ENSO), and 2) the Pacific Decadal Oscillation (PDO). Both are naturally occurring patterns, but their frequency and intensity appear to be changing in response to global climate change (Trenberth and Hurrell, 1994; Timmermann, 1999).

The ENSO is a tropical Pacific phenomenon that influences global weather patterns. It has a cycle of 3 to 7 years (Wolter and Timlin, 1993, 1998; *see* Chapter 2). During warm 'El Niño' events, warm waters from the equatorial Pacific migrate up the west coast of North America and influence sea-surface temperatures, sea levels, and local climate across BC. Impacts of ENSO are strongest in winter and spring. El Niños bring warmer temperatures (by 0.4–0.7°C) and less precipitation to BC, whereas cool 'La Niña' events bring cooler and wetter conditions (Climate Impacts Group, 2006).

The PDO is a longer (approx. 20–30 year) climate variability pattern similar in effect to ENSO, but it occurs in the midlatitude northeastern Pacific (Mantua et al., 1997). The positive (warm) PDO phase is characterized by warmer coastal waters in the northeastern Pacific. It is associated with slightly warmer conditions across BC during winter and spring, and variable effects on precipitation. The opposite occurs during the negative PDO phase, with cooler and wetter conditions. Shifts between PDO phases result in major changes in climatic and oceanographic regimes, affecting winds and storms, ocean temperatures and currents (Bond and Harrison, 2000; McPhaden and Zhang, 2002). The PDO shifted from a negative (cold) to a positive (warm) phase in 1976 (Hare and Mantua, 2000) and has been positive ever since, except for the late 1980s and early 2000s.

These two climate variability patterns are linked, since the PDO either amplifies or dampens the effects of ENSO events (Gershunov and Barnett 1998; Biondi et al., 2001), affecting not only temperature and precipitation but also snowpack, streamflow, growing degree days, frost-free periods, winds, seasonal ocean levels and storm surges. The effects of PDO and

ENSO in western North America are widespread and well documented (e.g. Fleming et al., 2006; Stahl et al., 2006; Wang et al., 2006).

Understanding these factors that control climate variability in BC is important for a wide range of planning purposes. Perhaps most important is that the use of short-term (30-year) climate averages cannot capture the variability introduced by the PDO. Second, the strong influence of ENSO means that seasonal climate predictions can be used for operational planning on a year-to-year basis (American Meteorological Society, 2001). Seasonal climate forecasts are presently available for some areas and seasons based on statistical relationships with climate variability patterns[6]. These forecasts can assist with risk assessments for forest fires, droughts, water and energy supply/demand, snow removal, river forecasting and flooding. Such predictions represent a major improvement over the use of historical information only. It has been estimated that incorporation of seasonal climate predictions into planning of hydroelectric reservoir operations on the Columbia River could increase annual revenues by an average of CDN$153 million (Hamlet et al., 2002).

### *Prehistoric Records of Variability and Change*

Natural archives, such as lake and ocean sediments, tree rings, glacial ice and landforms, provide insights into the climate variability and environmental history of British Columbia prior to the instrumental record. Extensive paleoclimatic research has been conducted in BC. Recent reviews document that, following a colder drier climate toward the end of the last glaciation (approx. 12 500 years ago), BC's climate warmed rapidly by 5°C over only a century or two (Hebda and Whitlock, 1997; Walker and Pellatt, 2003). Following this were three broad climate intervals: 1) a warm and dry interval from approximately 10 000 to 7400 years ago; 2) a warm and moist interval from 7400 to 4400 years ago; and 3) a cooler interval, analogous to the modern climate, from about 4400 years ago (Figure 4).

Superimposed on this longer term climate history is a complex pattern of climate variability that includes 1) abrupt changes in climate (Gedalof and Smith, 2001; Chang et al., 2003; Chang and Patterson, 2005; Zhang and Hebda, 2005); 2) periods of intense, persistent drought (Gedalof et al., 2004; Watson and Luckman, 2004, 2005); 3) inconsistent relationships between ENSO, PDO and the climate of BC (Gedalof et al., 2002, 2004; Watson and Luckman, 2004, 2005) and 4) multiple periods of alpine glacier advance and retreat (Ryder and Thomson, 1986; Luckman, 2000; Larocque and Smith, 2003, 2004; Koch et al., 2004; Lewis and Smith, 2004). In particular, the glacial record shows that current warming rates are unprecedented in the last 8000 years (Menounos et al., 2004). Together, these records demonstrate the dynamic nature of BC's climate and the great likelihood that climate 'surprises' will occur in the future.

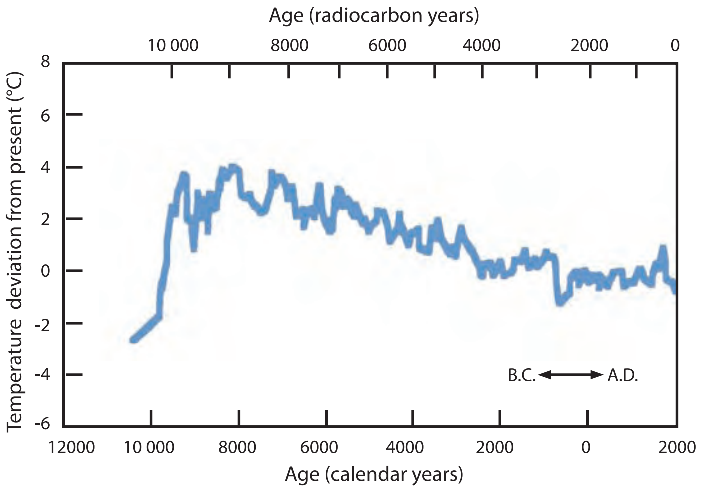


**FIGURE 4:** Inferred temperature records from southern British Columbia (*from* Rosenberg et al., 2004).

Three key lessons emerge from the prehistoric climate record that are of relevance to the assessment of future climate change:

- Abrupt changes in climate, similar to the shift in 1976, are common in the prehistoric record, as are abrupt changes in ocean circulation.
- Influences of large-scale patterns of climate variability (e.g. ENSO and PDO) on BC's climate have not been consistent in recent centuries. Consequently, the instrumental record probably does not reflect the full range of variability of the climate system, which may respond unpredictably to changes in forcing.
- Severe, sustained droughts occurred more frequently in previous centuries than over the past few decades, and would therefore be expected to occur in the future irrespective of climate change.

## 2.2 TEMPERATURE AND PRECIPITATION

### *Historical Trends*

Although there are several long-term instrumental climate records for British Columbia, most stations began recording around 1950, which presents challenges for the identification of long-term trends. The present-day climate station network (shown in Figure 1) is also not sufficiently dense to characterize adequately BC's highly variable climate (Miles and Associates, 2003). Regardless of length of record, however, all trends show that BC's climate has warmed significantly in recent decades (Zhang et al., 2000; BC Ministry of Water, Land and Air Protection, 2002; Whitfield et al., 2002a; BC Ministry of Environment, 2006). Longer records suggest that the rate of

---

[6] Seasonal climate predictions are available from various agencies and are published on the Internet. For a listing, *see* <http://www.pacificclimate.org/impacts/index.php?id=6> [accessed May 18, 2007].

change in temperature and precipitation in southern BC and much of the Pacific Northwest during the twentieth century exceeded global averages (Zhang et al., 2000; Mote, 2003a, c). Most of the province experienced warming in both mean annual temperature (Figure 5) and during all seasons (Table 1), although there are large regional and seasonal disparities in trends (Whitfield et al., 2002a). Annual and seasonal precipitation trends also vary by region (Figure 6, Table 2).

## *Future Projections*

Global climate models (GCMs) are used to project future climate with plausible scenarios of future greenhouse gas emissions and physical models of climate that include atmospheric, ocean, ice and land-surface components (*see also* Chapter 2). Multiple projections and/or models are used to address uncertainty and produce a range of possible futures.

**TABLE 1:** Historical trends in temperature in British Columbia's northern, southern and coastal regions.

| Region | Extremes | Seasonal | Annual |
|---|---|---|---|
| BC | Increased warm temperature extremes[1]; fewer extreme cold days and nights, fewer frost days and more extreme warm nights and days[2]; longer frost-free period[3] | Daily minimum and maximum temperatures higher in all seasons; greatest warming in spring and winter[3] | 0 ℃ isotherm shifting northward[4] |
| Southern BC | Interior warmed more than the coast[3] | Warming in spring, fall and winter, but not summer[5, 6] | |
| Northern BC | | Warmer winters, cooler falls[7] | Warmer average annual temperature[5] |
| Coastal BC | Coast warmed less than interior[3] | Warmer in spring and fall[8]; Georgia Basin–Puget Sound region warming in all seasons, especially last 30 years[9] | |

[1] Bonsal et al. (2001)
[2] Vincent and Mekis (2006)
[3] For the period 1950-2003 (B. Taylor, Environment Canada, pers. comm., 2007)
[4] Bonsal and Prowse (2003)
[5] Zhang et al. (2000)
[6] Whitfield et al. (2002a)
[7] Whitfield et al. (2003)
[8] Whitfield and Taylor (1998)
[9] Mote (2003a)

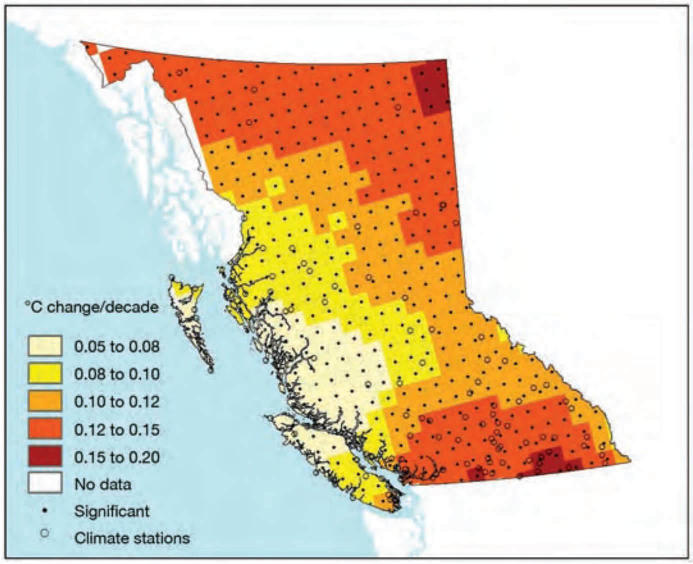


**FIGURE 5:** Trend in annual mean temperature (in °C per decade) for British Columbia, 1900–2004. Use of annual averages may mask seasonal trends that are larger than the annual average and/or of opposite sign. Long-term trends should be considered in the context of climate variability (*see* Section 2.1).

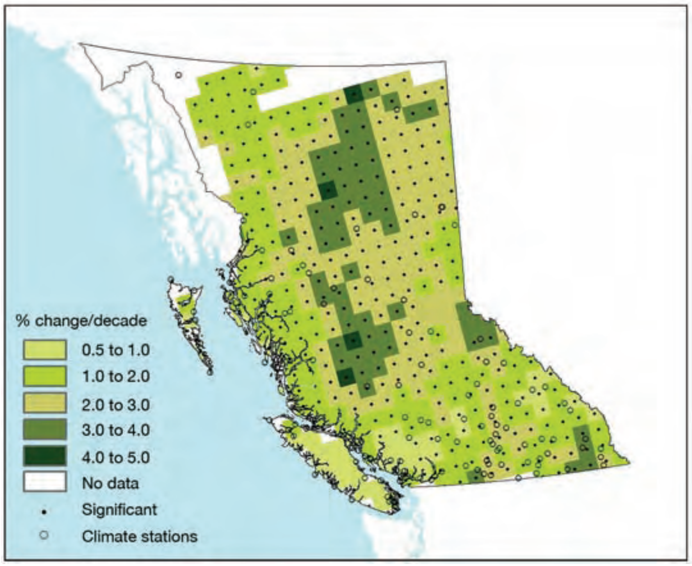


**FIGURE 6:** Trend in annual total precipitation for British Columbia, 1900-2004, in % change per decade from 1961-1990 (trends shown are relative to what is normal at a given location). See Figure 2 for the 1961-1990 average. Use of annual averages may mask seasonal trends that are larger than the annual average and/or of opposite sign. Long term trends should be considered in the context of climate variability (*see* Section 2.1).

**TABLE 2:** Historical trends in precipitation in British Columbia's northern, southern and coastal regions.

| **Region** | Extremes | Snow/rain | Total annual precipitation | Total seasonal precipitation |
|---|---|---|---|---|
| BC | More precipitation days, decreased consecutive dry days, decreased mean daily precipitation; no consistent changes in extremes[1] | Decreased snow to total precipitation ratio (more rain, less snow during cold season)[2] | Slightly wetter[2, 3] | |
| Southern BC | Wetter winter wet periods | Less annual snowfall in last 50 years[1]; ratio of rain to snow increased (more rain, less snow) in Okanagan[4]; decreased snowpack in spring and at lower elevations[5, 6, 7] | Wetter in 20th century, with majority of increase before 1945[8] | Wetter in spring, summer, fall[3]; drier in winter, wetter in summer in Okanagan[4]; drier in winter in interior[2] |
| Northern BC | | More snowfall since 1950s[1] | | Wetter in all four seasons[3] |
| Coastal BC | | Less snow throughout, more than 40% less at some sites[5]; greatest loss of snow in Pacific Northwest on south coast; more locations with no snow on April 1 | | Wetter in winter (more rain)[9], except Georgia Basin (no trend November to March) |

1 Vincent and Mekis (2006)
2 For the period 1950-2003 (B. Taylor, Environment Canada, pers. comm., 2007)
3 Zhang et al. (2000)
4 Whitfield and Cannon (in press)
5 Mote (2003a)
6 Mote (2003b)
7 Mote et al. (2005)
8 Mote (2003c)
9 Whitfield and Taylor (1998)

For BC, three large scenario regions (northern, southern and coast) were chosen for this assessment, based on large (approx. 100 km$^2$) GCM grids. Scenarios are displayed as changes from an observed 1961–1990 mean climate to the 2020s, 2050s and 2080s for temperature (Figure 7a) and precipitation (Figure 7b). Scenarios of precipitation by season[7] for BC suggest that conditions will be wetter over much of the province in winter and spring, but drier during summer in the south and on the coast.

Scenarios of finer spatial resolution are available using regional climate models (RCMs); however, the computational costs generally limit RCMs to fewer emissions scenarios than presented above. Downscaling methods, such as the ClimateBC program (University of British Columbia, no date) that uses high-resolution elevation and historical data to generate statistical predictions, also provide enhanced spatial resolution (Hamann and Wang, 2005; *see* Section 3.6 for application to parks adaptations).

## 2.3 EXTREME WEATHER AND WEATHER-RELATED EVENTS

Extreme weather and weather-related events directly affect British Columbians more than any other climate risk. Windstorms, forest fires, storm surges, landslides, snowstorms, hail and floods all have major impacts on communities, infrastructure and industry (Hamlet, 2003; Sandford, 2006). The impacts and steps toward adaptation for various climate-related extreme events are discussed in Section 4 (*see also* Sections 3.7 and 3.8). Increased occurrence of extreme weather events is documented worldwide, and climate models project a continuing rise in their frequency (Easterling et al., 2000; Milly et al., 2002; Palmer and Rälsänen, 2002; Schumacher and Johnson, 2005). In western North America, forest fires have become more frequent and severe with recent warming (Gedalof et al., 2005; Westerling et al., 2006), and this is projected to continue in western Canada (Gillett et al., 2004; Flannigan et al., 2005).

---

[7] Available from <http://www.PacificClimate.org> [accessed May 18, 2007].

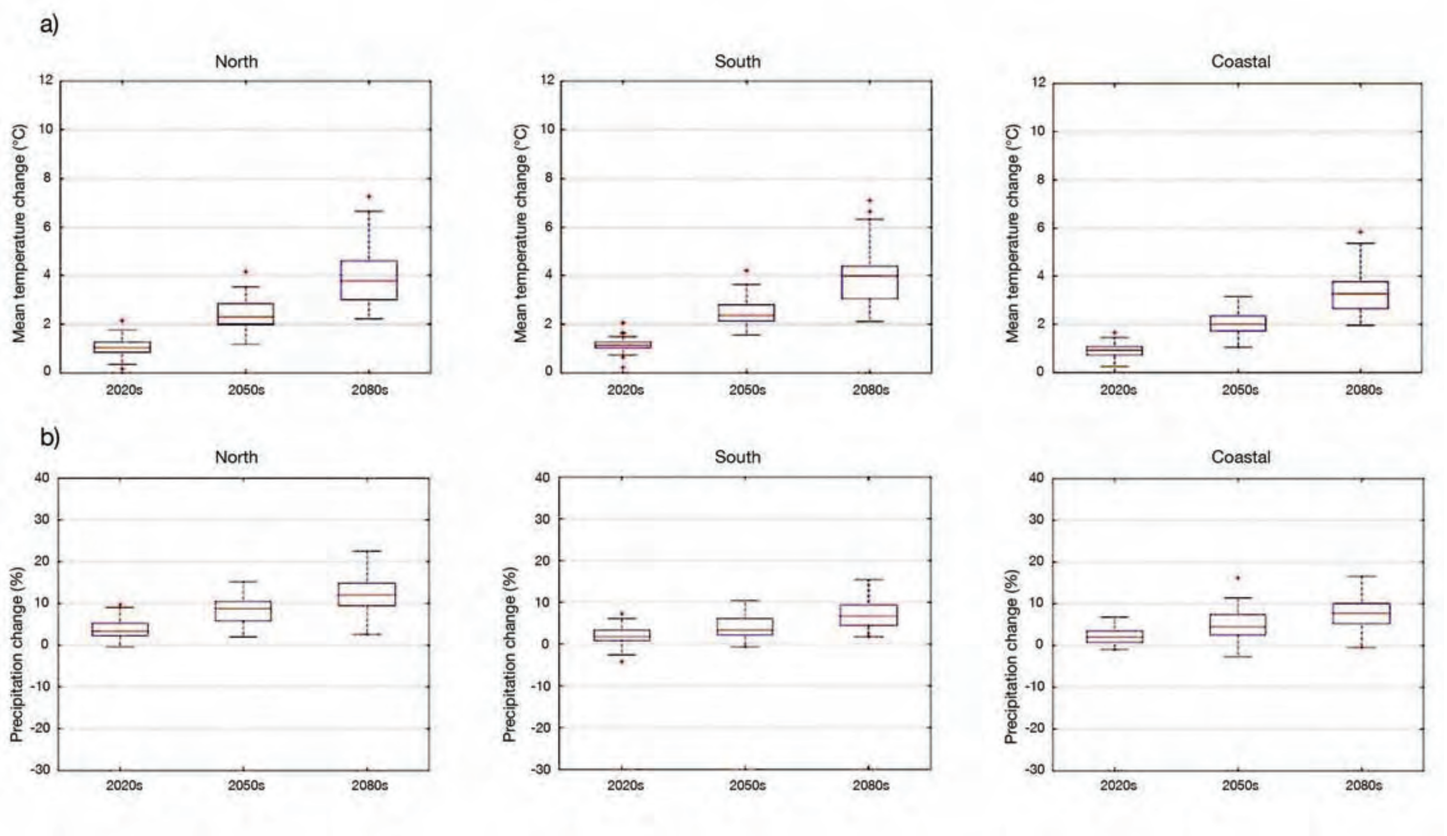


**FIGURE 7:** Changes from the 1961–1990 historical climate to the 2020s, 2050s and 2080s in a) temperature (°C), and b) precipitation (%). See Appendix 1 in Chapter 2 for description of box-and-whisker plots.

British Columbia's Provincial Emergency Program (BC-PEP) records extreme weather events that cause personal and economic losses due to infrastructure damage. From 2003 to 2005, the frequency, severity and costs of extreme events recorded by BC-PEP rose dramatically as a result of wildfires, storm surges, heavy rains causing flooding and landslides, and drought. Warmer winter weather, resulting in ice jams, freezing rain and rain-on-snow events, also resulted in economic losses. These events cost BC taxpayers an average of $86 million per year in payouts of disaster financial assistance, compared to an average of $10 million per year from 1999 to 2002 (Whyte, 2006). This increase is consistent with increasing weather-related hazards, as documented in the Canadian Disaster Database (McBean and Henstra, 2003; Public Safety and Emergency Preparedness Canada, 2006b).

## 2.4 HYDROLOGY

Regional hydrological changes are linked to temperature and precipitation trends (Tables 2 and 3; *see* Sections 3.1 and 4.3). Large temperature increases have resulted in a reduced snowpack, even in snowmelt-dominated basins where net

**TABLE 3:** Regional trends in river runoff in British Columbia.

| Location | Trend in runoff |
|---|---|
| Provincial trends | • Shifts in stream flows and seasonal transitions[1]<br>• Earlier spring runoff[2, 3]<br>• Increasing river temperatures[4] |
| Coastal | • Increased winter flows[5, 6]<br>• Decreased late summer flows[5] |
| Northern | • Streamflow increases throughout the year, particularly in winter[7] |
| Southern | • Extended lower flows in late summer and early fall[1]<br>• Longer periods of low flow[1]<br>• Higher early winter flows (southern interior)[1] |

[1] Leith and Whitfield (1998)
[2] Whitfield et al. (2003)
[3] Zhang et al. (2000)
[4] BC Ministry of Water, Land and Air Protection (2002)
[5] Whitfield and Taylor (1998)
[6] Whitfield et al. (2002b)
[7] Whitfield and Cannon (2000)

**BOX 1**

### BC's glaciers: a dwindling natural resource

Glaciers are a major source of fresh water for western Canada, with glacial runoff currently maintaining river discharge and regulating temperatures in many western Canadian rivers (Fleming, 2005; Fleming and Clark, 2005; Moore, 2006), supplementing surface runoff during the summer when aquatic ecosystems are most vulnerable and demand for water highest. For instance, in the Columbia River basin, 10 to 20% of annual flow and 50% of summer flows are glacier fed (Brugman et al., 1996).

In 2005, glaciers covered 3% of BC (30 000 $km^2$) and were retreating at rates unprecedented in the last 8000 years (Lowell, 2000). Most of BC's glaciers are losing mass and many will disappear in the next 100 years. Information on the rates and magnitude of glacier retreat is important for water resource management and planning, which has to address demands for human consumption, irrigation, industrial use and hydroelectric power generation, as well as in-stream ecological needs. Climate change and increasing water resource demands are expected to exacerbate existing supply-demand mismatches (Environment Canada, 2004). Decreasing summer flows resulting from reduced glacier melt, combined with increasing summer water demands to meet rising irrigation requirements and energy needs for cooling, presents one of the most significant water resource challenges for BC, a province seemingly blessed with water.

precipitation has increased (Mote, 2003a, b; Stewart et al., 2004). Reductions in snowpack have changed streamflow volumes and timing, while many lakes and rivers also show shorter periods of ice cover (BC Ministry of Water, Land and Air Protection, 2002) and earlier spring ice melt (Bonsal et al., 2001). Spring melt now occurs earlier in many BC rivers (Zhang et al., 2001a), a trend that climate model projections indicate will continue (Barnett et al., 2005). Also significantly impacting regional hydrology is the rapid melting of alpine glaciers, many of which may disappear in the next 100 years (Box 1).

Analysis for the entire Pacific Northwest suggests that historical streamflow trends will continue, with many rivers running 30 to 40 days earlier by 2100 (Stewart et al., 2004). Increasing temperatures and precipitation changes will reduce snowpack and increase winter runoff for most of BC (Hamlet and Lettenmaier, 1999; Mote and Hamlet, 2001). Reduced snowpack and earlier snow melt, combined with higher evapotranspiration, will result in earlier spring peak flows and reduced April to September streamflows. For example, by 2045 in the Columbia River basin, April to September runoff could be reduced by 10 to 25% relative to a simulated hydrological base case (Hamlet and Lettenmaier, 1999). Combined, these hydrological impacts will affect several of BC's key economic sectors, including hydroelectric power generation (*see* Section 3.7), fisheries (*see* Section 3.2) and agriculture (*see* Section 3.4).

Climate change also impacts groundwater systems, with the greatest changes evident in shallow aquifer systems (Rivera et al., 2004). Even small changes in temperature and precipitation alter groundwater recharge rates and water table depths (e.g. Changnon et al., 1988; Zektser and Loaiciga, 1993). Reductions in stream flow will have negative effects on both groundwater recharge and discharge (Scibek and Allen, 2006). As groundwater discharge serves to moderate stream temperatures, reduced summer discharge would result in even greater increases in surface water temperatures than would occur from air temperatures alone. In coastal regions, climate change will also impact groundwater quality due to saltwater intrusion in response to sea-level rise (e.g. Lambrakis and Kallergis, 2001; Yin, 2001).

## 2.5 SEA LEVEL

Globally, mean eustatic sea level increased 10 to 20 cm during the twentieth century, and is anticipated to rise another 18 to 59 cm by 2100, due largely to melting glaciers and ice sheets, and thermal expansion of warming seawater (Intergovernmental Panel on Climate Change, 2007). In British Columbia, relative sea-level change differs from the global trend due to vertical land movements. During the twentieth century, sea level rose 4 cm in Vancouver, 8 cm in Victoria and 12 cm in Prince Rupert, and dropped by 13 cm in Tofino (BC Ministry of Water, Land and Air Protection, 2002). Sea-level rise is an important issue in BC, as it impacts coastal infrastructure, such as highways, sewer systems, shipping terminals and Vancouver International Airport. For perspective, an arbitrary 1 m rise in sea level would inundate more than 4600 ha of farmland and more than 15 000 ha of industrial and residential urban areas in British Columbia (Yin, 2001). Approximately 220 000 people live near or below sea level in Richmond and Delta in Greater Vancouver, and are protected by 127 km of dykes that were not built to accommodate sea-level rise (B. Kangesneimi, BC Ministry of Environment, pers. comm., 2007). Many remote coastal communities and First Nations' heritage sites are vulnerable to enhanced erosion and storm-surge flooding associated with sea-level rise. Finally, sea-level rise can result in saltwater intrusion into freshwater aquifers, affecting the quality and quantity of drinking and irrigation water supplies (Liteanu, 2003; Allen, 2004).

On British Columbia's coast, the height of damaging extreme high-water events is increasing at a rate faster than sea-level rise (e.g. 22–34 cm/century at Prince Rupert, 16 cm/century at

Vancouver; BC Ministry of Water, Land and Air Protection, 2002; Abeysirigunawardena and Walker, in press). At Tofino, where relative sea level has fallen, the extreme high-water events show little change. Extreme sea levels, storm surges and enhanced coastal erosion are strongly influenced by ENSO and PDO (Storlazzi et al., 2000; Dingler and Reiss, 2001; Allan and Komar, 2002; Abeysirigunawardena and Walker, in press). Extreme water levels have increased significantly since the positive PDO shift of 1976 (Abeysirigunawardena and Walker, in press). During the El Niños of 1982–1983 and 1997–1998, sea levels from California to Alaska rose as much as 100 cm above average (Subbotina et al., 2001), and more energetic wave conditions produced extensive coastal erosion and infrastructure damage (Storlazzi et al., 2000; Allan and Komar, 2002). On BC's north coast, sea levels rose 10 to 40 cm above seasonal heights in 1997–1998 causing extensive localized erosion (Crawford et al., 1999; Barrie and Conway, 2002).

## 2.6 ECOSYSTEMS

Climate change impacts ecosystem distribution and biodiversity (*see* Sections 3.2, 3.3, and 3.6). Several consistent themes emerge from a wide range of studies:

- Pacific salmon, sardine, anchovy, mountain pine beetle and western red cedar have shown abrupt changes in abundance and/or distribution in response to past, relatively minor changes in climate (Robinson and Ware, 1994; Hebda, 1999; Ware and Thomson, 2000; Brown and Hebda, 2002, 2003; Wright et al., 2005). Such changes can have significant social and economic implications (*see* Sections 3.2 and 3.3).
- Large shifts in species ranges are expected to occur (Royal BC Museum, 2005a), often with little overlap between current and projected distributions (Shafer et al., 2001). Species will respond individually, and resulting vegetation communities may not resemble current communities (Brubaker, 1988; Gavin et al., 2001).
- Many of BC's specialized habitats (e.g. alpine ecosystems, deserts, cold steppe) will become reduced in extent and more fragmented (Shafer et al., 2001).
- The capacity of BC's system of protected areas to maintain biodiversity will be challenged, as many species will be forced to migrate over natural barriers (water, mountains) and human-induced landscape fragmentation (Overpeck et al., 1991; Dyer, 1995; Lemieux and Scott, 2005; *see* Section 3.6).
- Wildfire frequency and severity will increase in coming decades (Flannigan et al., 2001; Gillett et al., 2004; Gedalof et al., 2005; Westerling et al., 2006). While this will likely present challenges for some ecosystems, others (e.g. Garry oak and ponderosa pine forests), which are fire maintained, may expand in range (Agee, 1993; McKenzie et al. 2004).
- Large-scale outbreaks of pests, such as mountain pine beetle and spruce bark beetle, are expected to persist and expand with continued warming. These pose an increasing threat to species such as high-elevation whitebark pine and eastern jack pine forests across western Canada (Logan and Powell, 2001; *see* Section 4.2).

## 2.7 SUMMARY

Key findings regarding ongoing and future climate changes in British Columbia include the following:

- Major shifts in climate variability and extremes are inherent to the system and can be expected in the future. Climate changes in BC during the twentieth century exceeded most global trends, with considerable regional variability.
- British Columbia's climate is substantially influenced by large-scale variability patterns, including ENSO and the PDO. Associated extreme weather events are increasing, and resulting damage costs are on the rise.
- Increasing temperatures have resulted in decreased snow accumulation in many locations, particularly at low elevations.
- British Columbia's glaciers are retreating at rates unprecedented in the last 8000 years, with implications for existing and future water and energy demands, agriculture and aquatic ecosystems.
- Vegetation reconstructions show that plant species respond individually to climate change. Future ecological changes will be complex and potentially rapid.
- British Columbia could warm by 2 to 7°C by 2080. Biophysical impacts will include sea-level rise, changing frequency and magnitude of precipitation and extreme events, major hydrological changes and reorganization of ecosystems.
- Seasonal climate forecasts incorporating ENSO and PDO effects are useful for year-to-year operational planning, but are currently underutilized.
- Instrumental records used to compute climate normals, trends and probabilities of extreme event occurrence (floods, droughts, storms) are often too short, and assume static (unchanging) conditions, and are therefore inadequate for many planning purposes.

# 3 SECTORAL IMPACTS AND ADAPTIVE CAPACITY

How biophysical changes affect British Columbia's society depends on social and economic factors at both local and regional scales. The vulnerability of people and communities to climate change risks is a function of their physical exposure to natural hazards, their interdependencies with the natural environment (e.g. natural resources) and their adaptive capacity (Dolan and Walker, 2007; *see also* Chapter 2). Although the trend towards a more diversified economy improves the adaptive capacity of the BC economy as a whole to climate change and other stressors, it is unlikely that such diversification will be evenly distributed across all regions and sectors.

Climate change will impact economic development in BC, in ways that range from changes in domestic natural resources (e.g. forests, water and wilderness) to changes in the geography of optimal land-use activities (e.g. high-value agriculture crops, forage crops and commercial forestry) to increases in the social and economic costs associated with expected increases in extreme weather events.

The following sections examine how different economic sectors of BC are being impacted by changing climate, including, where possible, discussion of current and possible future adaptation initiatives.

## 3.1 WATER RESOURCE MANAGEMENT

Water resources, and their management and use, are highly sensitive to climate variability and change. Water managers will be challenged to meet multiple, often competing objectives (energy, irrigation, navigation, flood control, in-stream requirements) under conditions of changing supply and demand.

### *Surface Water*

British Columbia has immense water resources, with approximately one-third of Canada's surface water. The implications of climate change for management of surface water resources have received considerable attention in the Columbia River basin (cf. Hamlet and Lettenmaier, 1999; Mote et al., 1999; Miles et al., 2000), including consideration of transborder issues (Cohen et al., 2000; Hamlet, 2003; Payne et al., 2004). As discussed above (Section 2.4), climate-induced changes in hydrology, including reduced snow pack and earlier snowmelt peaks, have significant implications for regional water supplies and fisheries. Increased flows during winter months and an earlier flood season will result in less water flowing during the summer months, when irrigation demand is highest. Reduced summer flows will also affect hydroelectricity generation and salmon habitat. It will be difficult to achieve current management objectives for both hydroelectric generation and in-stream flows to support fisheries under virtually all future climate scenarios (Payne et al., 2004). Within the Fraser River basin, a longer low-flow period could elevate summer stream temperatures by almost 2°C, with serious implications for fisheries (Morrison et al., 2002; Loukas et al., 2004). Hydrological scenarios for the Okanagan valley and implications for fisheries are discussed in detail in Section 4.3.

Although some research is available on hydrological impacts in the Liard River and Peace River basins of northeastern BC (*see* Cohen, 1997), climate change has not been considered in current management plans. For example, although the Peace River Water Use Plan includes reduction of greenhouse gas emissions as a management goal, it does not discuss management options for the hydrological changes that will be associated with climate change (BC Hydro, 2004).

### *Groundwater*

Approximately 600 000 people (22% of British Columbia's population) rely on groundwater as a source of drinking water (BC Ministry of Environment, Land and Parks, 1993). Agriculture and industry, including irrigation, pulp and paper, fish hatcheries, food processing, mining, chemical and petrochemical industries, parks and airports, are all major users of groundwater in the province (Liebscher, 1987). To date, more than 600 aquifers have been mapped and classified according to the BC Aquifer Classification System[8].

In addition to the direct impact of climate change on groundwater tables and quality (*see* Section 2.4), increased demand for groundwater is anticipated in areas of the province where surface-water systems are unable to meet consumptive and in-stream demands. In some areas, such demands may necessitate deepening water supply wells to access deeper aquifers that are less sensitive to changing climate (Rivera et al., 2004).

---

[8] The website <http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/index.html> [accessed April 30, 2007] provides information on aquifiers in British Columbia and a link to the Aquifier Classification Database.

## 3.2 FISHERIES

The fisheries and aquaculture sector, including commercial and sport fishing, aquaculture and seafood processing, employs about 20 000 people throughout British Columbia (BC Ministry of Agriculture and Lands, 2005a; Table 4). In 2004, BC seafood had annual raw-harvest and processed wholesale values of $620 million and $1.1 billion, respectively (BC Ministry of Agriculture and Lands, 2005a). Sport fishing, with important links to tourism (*see* Section 3.5), forms the largest single component, accounting for around 8900 jobs and contributing about $233 million per year to provincial GDP (BC Ministry of Agriculture and Lands, 2004). British Columbia aquaculture includes 700 site licenses for 30 species of fish, shellfish and marine plants. Aquaculture sales increased rapidly from $3 million in 1983 to more than $212 million in 2005 (BC Ministry of Agriculture and Lands, 2005a). Nevertheless, the fisheries sector accounted for less than 1% of provincial GDP in 2001 (BC Ministry of Labour and Citizens' Services, 2006).

Fisheries, and species such as Pacific salmon, are also keystone contributors (*sensu* Garibaldi and Turner, 2004) to the social, cultural, legal and ecological fabric of British Columbia (Pearse, 1982; Glavin, 1996). Sustainable fisheries, and the status and trends of wild salmon in particular, are viewed as vital indicators for maintenance of ecosystem integrity. Moreover, constitutional guarantees of access to fish to meet the food, cultural and societal needs of Aboriginal peoples make the maintenance and restoration of traditional fisheries key elements in treaty negotiations throughout BC (Raunet, 1984; Harris, 2001). Economic impacts on the fisheries sector therefore have important consequences for activities in other sectors (e.g. agriculture, forestry, mining, energy development and urban development).

**TABLE 4:** British Columbia's fisheries and aquaculture sector (BC Ministry of Agriculture and Lands, 2005a).

| Sector | Sector revenue (millions of dollars) | Contribution to BC's gross domestic product (millions of dollars) | Contribution to BC's employment (thousands of jobs) |
|---|---|---|---|
| Commercial fisheries | 358 | 170 | 5.4 |
| Aquaculture | 287 | 116 | 1.9 |
| Seafood processing | 602 | 82 | 3.9 |
| Sport fishing | 675 | 233 | 8.9 |
| **Sector total** | **1922** | **601** | **20.1** |

During the past century, fisheries in British Columbia have changed in response to many factors (Box 2), including climate variability. The relationships between climate variability and the many physical variables affecting BC fish populations have been summarized for freshwater (Northcote, 1992) and marine environments (King, 2005; Fisheries and Oceans Canada, 2006a). These relationships make it clear that climate change will induce a wide range of responses from fish and fisheries in BC.

Sensitivity to climate variability and change varies greatly between short-lived species, such as shrimp, salmon, herring and sardines, and long-lived species, including geoduck clams, ocean perch and halibut (Fisheries and Oceans Canada, 2001). Short-lived species respond quickly to changes in climate, and populations can collapse or recover without warning, as evidenced by sardines (Hargreaves et al., 1994), herring (Schweigert, 1993) and salmon (McKinnell et al., 2001; Hyatt et al., 2003; Riddell, 2004; Fisheries and Oceans Canada, 2006b, c). Climate- or fishery-induced production trajectories of longer lived species change slowly, sometimes over a decade or longer, allowing greater predictability of fisheries yield, as in the case of halibut (Clarke and Hare, 2002). These differences between species will affect adaptation decisions.

**BOX 2**

### Fisheries sector trends in British Columbia

Halibut, herring, sardines, hake and salmon have supported major fisheries in BC since the late 1800s (Fisheries and Oceans Canada, 2001). Salmon fisheries have been dominant from a socioeconomic perspective for much of the past century. Salmon catch reached historical highs in the 1980s, followed by extreme lows in the 1990s (Beamish and Noakes, 2004) due to changes in marine productivity (Hare and Mantua, 2000; Beamish et al., 2003), management agency objectives (e.g. protect biodiversity; Hyatt and Riddell, 2000; Irvine et al., 2005) and low prices for wild salmon due to increased competition from aquaculture (Noakes et al., 2002). Currently, wild-capture fisheries are stable (major groundfish species and most invertebrates) or decreasing (e.g. salmon), whereas aquaculture production is increasing (Fisheries and Oceans Canada, 2001). Despite changing conditions, the fisheries sector has maintained an average landed value of $550 million (range $380–720 million) since 1985 (BC Ministry of Agriculture and Lands, 2002).

Fisheries responses to climate change will vary greatly among regions (Ware and McFarlane, 1989; Ware and Thomson, 2005). In freshwater ecosystems, climate change is already affecting the quantity (lake levels, river flow) and quality (temperature, nutrient levels) of seasonal to annual water supplies around Georgia basin (Whitfield et al., 2002b; Quilty et al., 2004), the Fraser River basin (Morrison et al., 2002) and the BC southern interior (*see* Sections 2.4 and 3.1), disrupting life histories and production of resident and migratory salmonids (Levy, 1992; MacDonald et al., 2000; Hyatt et al., 2003).

The Georgia Strait and the coastal upwelling zone west of Vancouver Island support some of the richest marine fisheries in BC (Ware and McFarlane, 1989). Studies of prehistoric (Wright et al., 2005) and historical intervals (Fisheries and Oceans Canada, 2006a) suggest that species dominance in these areas is highly variable, with salmon, herring and resident hake being most prevalent during cool conditions and migratory hake, along with such 'exotic' species as mackerel, tuna and even Humboldt squid, infiltrating from the south during warm conditions (Fisheries and Oceans Canada, 2006a). Experience suggests that economic gains from harvest of larger quantities of migratory hake (Ware and McFarlane, 1995), sardine (McFarlane and Beamish, 1998) and tuna under a warmer regime will not immediately offset losses from collapses of higher value (Table 5) salmon fisheries (Hyatt et al., 2003; Fisheries and Oceans Canada, 2006a). In addition, established coldwater fisheries have mature infrastructure (catching and processing capacity, established markets and fisheries management systems) that is lacking in new fisheries for exotic species. Economic dislocation and social stress in fisheries-dependent communities are likely to increase as climate continues to change, with losses from traditional fisheries exceeding returns from efforts to develop new ones or to replace them with aquaculture operations. Outcomes like these stress small coastal communities in particular, given their high reliance on traditional fisheries (Ommer, 2006, 2007).

Climate impacts on fisheries in the area of the Queen Charlotte basin are less certain. The historical effects of warmer waters, altered production regimes (e.g. King, 2005; Ware and Thomson, 2005) and exotic species have not produced obvious declines of herring and salmon in this region. In fact, some evidence suggests increased production of these species during warmer intervals (Boldt et al., 2005).

Many BC salmon rear for 1 to 4 years in the offshore waters of the Gulf of Alaska, so climate change in that region will impact salmon distribution (e.g. displacement to the Bering Sea; Welch et al., 1998). Changes in thermal stratification, nutrient delivery, primary production (Behrenfeld et al., 2006) or even ocean acidification (Raven et al., 2005) could profoundly influence salmon and fisheries production throughout BC. The ultimate consequences of such complex changes are unknown, but likely place southern rather than northern fisheries at greater risk of future losses.

**TABLE 5:** Total catch and maximum age of finfish supporting major fisheries (landed value greater than $1 million) on Canada's west coast as of 2002 (*adapted from* BC Ministry of Labour and Citizens' Services, 2002; King and McFarlane, 2003).

| Species group | Maximum age of fish (years) | Total weight (metric tons) | Average landed value[1] (millions of dollars, 1985-2002) | Approximate value[1] in 2002 (millions of dollars) |
|---|---|---|---|---|
| Rockfish | 58–205 | 15 236 | 10 | |
| Sablefish | 113 | 3 947 | 25 | 21 |
| Ocean perch | 100 | 6 179 | 5 | 6 |
| Pacific halibut | 55 | 6 096 | 30 | 43 |
| Pollock | 33 | 1,044 | 1 | |
| Lingcod | 25 | 1 984 | | |
| Pacific cod | 25 | 708 | 4 | 1 |
| Pacific hake | 23 | 22 347 | 12 | 12 |
| Pacific herring | 15 | 27 725 | 60 | 50 |
| Sardine | 13 | 800 | | |
| Tuna albacore | 10 | 233 | | |
| Chinook and coho salmon | 4–8 | 540 | 500 | 600 |
| Sockeye salmon | 7 | 8 670 | 100 | 40 |
| Chum salmon | 7 | 2 780 | 20 | 3 |
| Pink salmon | 3 | 7 160 | 20 | 5 |
| **Total** | | | **$787 million** | **$781 million** |

[1] Values identified here refer to landed value for all species except chinook and coho salmon, for which recreational fisheries in marine and tidal waters generate much higher revenues.

## *Adaptation*

Three public enquiries in the past 15 years (Pearse and Larkin, 1992; Fraser River Sockeye Public Review Board, 1995; Williams, 2005) considered causes, consequences and solutions for precipitous declines in production and harvest levels for southern coho, steelhead and Fraser River sockeye salmon (Fisheries and Oceans Canada, 2006b). Economic losses to the commercial sockeye fishery alone were estimated at $72 million in 2002, and likely exceeded this in 2004 (Cooke et al., 2004). Each enquiry identified a complex set of factors driving the declining fishery, including climate-induced production losses and associated management uncertainties. Declines of salmon in the Fraser River and elsewhere have stimulated initiatives calling for agencies and society to safeguard the productive capacity of habitats for wild fish and fisheries, given rapid human population increases combined with climate change threats in BC (Pacific Fisheries Resource Conservation Council, 2006). Without adaptation, continued reductions or elimination of salmon could occur in extensive areas of the BC interior and Georgia basin, where cumulative human impacts (Slaney et al., 1996), plus climate-induced changes to flow and temperature conditions (Rosenau and Angelo, 2003), have created significant problems for maintenance of fish populations and habitat. Conflicts over meeting the requirements for fisheries habitat as well as the water needs of other sectors (e.g. mining, agriculture, energy, urban development) are certain to intensify in the future.

Awareness of climate-induced impacts on the fisheries sector, relative to non-climatic factors, varies greatly among recreational, commercial, First Nations and management agency groups. Multi-party discussions at recent colloquia suggest a growing awareness that fisheries are unlikely to return to a state of business-as-usual (Interis, 2005), and that a range of adaptive responses will be required to meet challenges posed by climate change. Specific adaptation measures that have been discussed include 1) reducing harvest rates to provide conservation buffers, given increasingly variable stock productivity (Mantua and Francis, 2004); 2) reinforcing habitat protection and restoration measures by all sectors to promote increased sustainability of capture fisheries; 3) increasing hatchery production of salmon to counter declining productive capacity of freshwater or marine habitat; 4) licensing and regulating river systems; or 5) promoting accelerated development of aquaculture to meet market demands for products that capture-fisheries cannot satisfy. Shifting harvest opportunities provided by short-lived versus long-lived species, or from established (e.g. salmon, herring) to relatively unexploited species (e.g. mackerel, squid) may require a different suite of adaptation measures. These might involve licensing processes that promote participation in multiple fisheries for a diversity of short- and long-lived species, and increased investment to speed the development of processing, marketing and management infrastructure for newly emergent fisheries.

## 3.3 FORESTRY

British Columbia's 62 million ha of forest provide a wide range of social, cultural, economic and biological values and services (Gagné et al., 2004; Forest Products Association of Canada, 2006). Approximately 0.3% of BC's forests are harvested annually, and fire protection is the only management activity currently practiced over a large area of the land base.

The current age distribution of forests in BC is skewed toward old trees, resulting in increased sensitivity to disturbance by fire and pests (Cammell and Knight, 1992; Dale et al., 2001; Volney and Hirsh 2005). Climate changes are considered a contributing factor to recent increases in fire activity (Gillett et al., 2004) and outbreaks of the mountain pine beetle (Carroll et al., 2004) and needle blight (Woods et al., 2005). As illustrated by the Kelowna and Barriere fires in 2003, forest fires have a direct impact on property and safety (Volney and Hirsch, 2005), with health impacts extending considerable distances from the fire. The economic and social impacts of mountain pine beetle are discussed in detail in Section 4.2. Continued climate change is expected to further increase disturbance risks, and involve other pest species, such as the leader weevil (Sieben et al., 1997). Coastal forests will likely see an increase in the number and intensity of storms, thereby increasing windthrow damage. Drier areas of the southern interior may experience regeneration problems due to an increase in summer droughts.

Climate change directly affects tree species, as optimum growth conditions for local populations can be relatively narrow (Rehfeldt et al., 1999, 2001; Parker et al., 2000; Wang et al., 2006). Consequently, although species may survive in their current location under a changed climate, growth rates will be affected and there will be increased competition from other species more suited to the climate. The potential ranges of species will move northward and upward in elevation (Cumming and Burton, 1996; Hebda, 1997; Hansen et al., 2001; Hamann and Wang, 2006), although species migration will be constrained by barriers to movement, slow migration rates, unsuitable soils or lack of habitat (Stewart et al., 1998; Gray, 2005). Overall, losses in productivity of natural and planted stands are expected to occur in the drier and warmer regions of BC, while modest increases are anticipated in the north (Rehfeldt et al., 1999, 2001; Spittlehouse, 2003; Johnson and Williamson, 2005).

Forestry operations will be impacted directly by climate change. Changes in productivity will affect rotation ages, wood quality, wood volume and size of logs. Access to timber may be limited during both winter, because of warmer and wetter conditions, and summer, due to increased fire risk. Increases in the frequency and magnitude of extreme precipitation will affect design and maintenance of logging roads (Bruce, 2003; Spittlehouse and Stewart, 2003), and increase the probability of landslides and debris flows (Wieczorek and Glade, 2005). Impacts on the forest sector will also be influenced by technological changes, trade issues and changes in consumer preferences that will take place concurrent with climate change. Countries that are expected to see significant production benefits from a changing climate, particularly those in South America and Oceania, are already replacing BC products in the global market (Perez-Garcia et al., 2002; Sohngen and Sedjo, 2005). Such changes affect forestry product supply-demand dynamics.

### *Adaptation*

The long growth period before trees are harvested means that the wood supply for the next 50 or more years is already 'in the ground'. As a result, short-term adaptations will focus primarily on operational changes. Already, the increase in disturbance by fire and insects has resulted in greater amounts of the harvest being salvaged wood, a trend that will continue in the future (Spittlehouse and Stewart, 2003; Volney and Hirsch, 2005). Forest management adaptation will also have to consider climate change impacts beyond those directly affecting timber resources, in order to maintain biodiversity and ensure landscape connectivity (cf. Harding and McCullum 1997; Stenseth et al., 2002; Mote et al., 2003; Moore et al., 2005). In addition, increased competition from species more suited to changed climate conditions may create a need for increased management activities in established stands (Parker et al., 2000; Spittlehouse and Stewart, 2003; Spittlehouse, 2005).

Longer term adaptation measures include changes in reforestation practices, especially species selection, as the tree types best suited to particular sites change (Rehfeldt et al., 1999; Parker et al., 2000; Spittlehouse and Stewart, 2003). Wang et al. (2006) showed that a mid-range climate change scenario for BC shifts seed planting zones for lodgepole pine many hundreds of kilometres north. However, matching planting stock to new climate regimes is further complicated by the climate continuing to change over the life of the stand. In this case, planting genotypes that grow well under a wide temperature range could help maintain productivity at some sites in BC (Wang et al., 2006).

Although consideration of weather and climate is part of forest management, current policies on forest utilization and preservation are based on understanding how forests developed under past climatic conditions. This may limit the ability of the sector to respond optimally to both the negative and potentially positive impacts of climate change on different forest regions.

There are presently no requirements or guidelines to include climate change adaptation measures in forest management plans, and there are limited experienced personnel to aid such activities (Spittlehouse and Stewart, 2003; Spittlehouse, 2005). As most of BC's forests are on crown land, the provincial government is responsible for setting policies, developing management objectives and approving forest company stewardship plans. The government also sets standards for species selection, seed transfer and stocking; allocates land to parks and wilderness areas; and is responsible for maintaining forest health and growth-monitoring plots. In this context, Spittlehouse (2005) noted the need for more comprehensive assessment of vulnerability to climate change and developing and applying adaptation measures for forest management. The actions of the BC Ministry of Forests and Range outlined in Section 4.2.2 are a first step in this process.

## 3.4 AGRICULTURE

British Columbia's mountainous landscape and climatic diversity result in only 4.5% of land being suitable for farming. The protection of this limited resource was a major factor in the creation of a 4.7 million ha Agricultural Land Reserve (ALR) in 1974. The ALR is a useful institutional tool to help manage and maintain the province's agricultural resources under climate change and other compounding demands.

More than 200 major commodities are produced by BC's agri-food industry, which directly and indirectly employs about 290 000 people, or about 14% of the province's employed labour force (BC Ministry of Agriculture and Lands, 2005a). The primary industry is relatively small, but spin-offs in the food processing, wholesaling, retailing and food service sectors are worth more than $22 billion per year in consumer sales (BC Ministry of Agriculture and Lands, 2005b). Nearly 60% of the food needs of British Columbians are produced in the province (Smith, 1998), and BC exports food products valued at more than $3.4 billion (BC Ministry of Agriculture and Lands, 2005a, b). Agricultural production is concentrated in rural communities, where it provides stability to local resource-based rural economies.

The vulnerability of the agricultural sector in BC is a product of the interaction of specific climate changes with global and regional issues, including new markets and competitors, and production and transportation costs (Heinberg, 2003). Recent trends in the agriculture sector include a declining role in BC's economy; increased reliance on imports from other parts of Canada, the United States and Mexico; increased production of nursery and greenhouse products; declines in food processing capacity; increasing concerns surrounding food safety; and declines in consumer demand for meat products (BC Ministry of Agriculture and Lands, 2005a). Non-climatic risks to the agriculture sector include loss of arable land through development and urban sprawl, an increasingly competitive global market, and unmanageable and unpredictable markets.

Potential effects of climate change have been previously assessed for agriculture in British Columbia (Table 6) based on expert judgment (Zebarth et al., 1997). In all areas of the province, longer growing seasons and milder winters were expected to increase the range of crop types suitable for economic production. Increasing requirements for irrigation were predicted for the south coast and southern interior regions, with possible water shortages caused by reduced precipitation, limited water storage capacity and competition from burgeoning urban populations. The greatest potential for development was considered to be in the northern interior and Peace River regions, with large areas of currently uncultivated land becoming increasingly suitable for agriculture. Lack of infrastructure for water supply, transportation and distance from markets, however, were considered barriers to agricultural development in these areas.

It is likely that crop production areas will adjust to accommodate a changing climate and that some producers will be able to take advantage of new opportunities to grow different, and perhaps more valuable, crops (Zebarth et al., 1997). In BC, crop production areas are defined by soil productivity, water availability and climate. Growing regions for annual crops are limited by length of the growing season and heat units (growing

**TABLE 6:** Current and future climate limitations to crop production (Zebarth et al., 1997).

South coastal region

| | |
|---|---|
| **Current climate:** | **Future temperature:** |
| Mild, wet climate. | Projected to increase 2–3°C |
| Mean annual temperature: 10°C. | **Future precipitation:** |
| Mean annual precipitation: 800–1700 mm, 70% of which falls between October and March | Projected to increase from November to May (5–10%)<br>Projected to decrease from June to October (10–20%) |
| Frost free period: 175–240 days | |

| Type of agriculture | Current agriculture | Climate limitations | Effects of future temperature change | Effects of future precipitation change |
|---|---|---|---|---|
| Horticulture | Small fruit: raspberry, strawberry, blueberry<br>Field vegetables: corn, potato, cabbage family crops, salad crops | Perennials: summer moisture deficits, require some irrigation<br>Raspberries: winter damage from Arctic outflow<br>Field vegetables: low temperatures, wet soil conditions in spring | Warmer summer: increased productivity<br>Warmer winter: longer growing season; increased viability of bell pepper, melon, overwintering cabbage family crops and double cropping<br>Increased winter precipitation could limit annual crop production in water-logged soils<br>Decreased summer precipitation could mean that more irrigation is required<br>Reduction in diseases due to drier conditions could favour berry production | Increased winter precipitation could limit annual crop production in water-logged soils<br>Decreased summer precipitation could mean that more irrigation is required<br>Reduction in diseases due to drier conditions could favour berry production |
| Forage crops | Grass: pasture, hay, silage<br>Corn: silage | Grasses: winter damage from Arctic outflow<br>Forage crops: summer moisture deficit, require irrigation on Vancouver Island | Warmer spring: earlier harvest of forages<br>New, heat tolerant forage species required | Increased spring precipitation could limit harvest and quality of forages<br>Dry, hotter summer could mean that irrigation will be required in Fraser River valley |
| Greenhouse | Vegetables: cucumber, tomato, bell pepper<br>Ornamentals | | Warmer winter: lower heating costs, increase in tropical species<br>Hotter summer: higher cooling costs | |
| Other effects | | | Increased pest pressure: winter survival of pests and diseases, more life cycles | Flooding, soil drainage, soil compaction, increased leaching of agricultural chemicals |

**TABLE 6:** *(Continued)*

**Southern interior region**

**Current climate:**
Mean annual temperature: 2–5°C
Mean annual precipitation: 250–540 mm
Frost free period: 110–180 days

**Future temperature:**
Projected to increase 2–3°C
**Future precipitation:**
Projected to increase from November to May (0–15%)
Projected to decrease from June to October (0–10%)

| Type of agriculture | Current agriculture | Climate limitations | Effects of future temperature change | Effects of future precipitation change |
|---|---|---|---|---|
| Horticulture | Perennials: apple, pear, peach, plum, cherry, wine grape<br>Field vegetables: tomato, pepper, eggplant, cucumber | Perennials: summer moisture deficits could require irrigation; winter damage from Arctic outflow<br>Field crops: summer moisture deficits could require irrigation | Warmer winter: longer growing season; new, longer season varieties; reduced risk of cold damage<br>Earlier spring: increased frost risk<br>Warmer summer: increased risk of poor fruit quality<br>Warmer summer: higher grape quality | Increased winter precipitation could keep soils wet and reduce risk of cold damage to roots; could improve spring moisture availability<br>Decreased summer precipitation could mean that more irrigation is required<br>Reduction in diseases due to drier conditions; reduction in cherry splitting |
| Forage crops | Grass: pasture, hay, silage<br>Others: alfalfa, corn, cereals<br>Extensive dry rangeland | Summer moisture deficit may require some irrigation<br>Low winter temperatures may limit production | Warmer spring, longer growing season: more harvests of forages, more range grazing<br>New, heat-requiring species viable (silage corn) | |
| Greenhouse | Vegetables: cucumber, tomato, bell pepper<br>Ornamentals | | Warmer winter: lower heating costs.<br>Hotter summer: higher cooling costs | |
| Other effects | | | Increased risk of limited water supply for irrigation<br>Increased pest pressure: winter survival of pests and diseases, more life cycles. | Increased risk of limited water supply for irrigation |

**Northern interior region**

**Current climate:**
Mean annual temperature: 2–5°C
Mean annual precipitation: 450–600 mm
Frost free period: 110–180 days

**Future temperature:**
Projected to increase 2–3°C
**Future precipitation:**
Projected to increase from October to May (0–10%)
Projected to decrease from June to September[1] (5–20%)

| Type of agriculture | Current agriculture | Climate limitations | Effects of future temperature change | Effects of future precipitation change |
|---|---|---|---|---|
| Forage crops | Grass: pasture, hay, silage<br>Cereals<br>Extensive natural rangeland | Summer moisture deficit may require some irrigation<br>Low winter temperatures may limit production<br>Short growing season will limit choice of crops | Warmer spring: longer growing season, higher productivity, more range grazing<br>New, heat-requiring species viable (silage corn) | |
| Other effects | | | Increased risk of limited water supply for irrigation<br>Increased pest pressure: winter survival of pests and diseases, more life cycles | Increased risk of limited water supply for irrigation |

[1] except August (increase of 5%)

degree days, or GDD). Perennial crops are limited primarily by winter minimum temperatures, but also by length of growing season and GDD. Current agricultural land-use patterns are based on long-term experience, and defined by climate and the frequency of extreme weather events (Caprio and Quamme, 1999, 2002, 2006). Under a moderate climate change scenario, projected changes in GDD (Royal BC Museum, 2005a) indicate that, by 2020, there would be potential to grow cereals, cabbage and potatoes (1000–1500 GDD) on much of the Interior Plateau, and corn and tomatoes (1500–2000 GDD) along the Fraser River as far north as Prince George. By the 2050s, GDD would be sufficient to potentially support growth of corn and tomatoes in the Peace River area and in northern coastal valleys. Full understanding of changes in agricultural suitability, particularly for perennial crops, requires assessment of future growing season length, boundaries for extreme minimum winter temperatures and the potential for irrigation in water-limited regions, as well as development of detailed soil maps for non-agricultural areas. Estimations of potential future land-use patterns also need to consider topographically defined microclimates, which ultimately determine crop location (e.g. Bowen et al., 2006).

In all areas of BC, the possibility of increased summer drought, coupled with decreasing water resources, will provide challenges for water supply to support irrigation (Zebarth et al., 1997; Neilsen et al., 2004a, b). In areas that are highly or entirely dependent on irrigation, such as the Okanagan basin, economic production requires timely availability of water, both to assure quality and to protect investment in perennial plants. The risks associated with drought are determined by the severity and frequency of drought conditions (Neilsen et al., 2006). For the Okanagan (*see* Section 4.3.2) and other regions, a key adaptation by the agriculture sector will likely involve conservation irrigation practices (Neilsen et al., 2001, 2003), including deficit irrigation, where water is underapplied to enhance crop quality and reduce consumption (Dry et al., 2001).

Although few data are available for BC, increased summer and winter temperatures may also result in new agricultural pests and diseases.

### *Risk Perception and Adaptation*

Agricultural producers are accustomed to dealing with uncertainty in weather, markets, pests and diseases, and potential income. Grower surveys in the Okanagan region showed that producers face weather-related risks, risks from market factors and risks from the impacts of pests and diseases on crop quality and quantity (Belliveau et al., 2006a, b; *see* Section 4.3.2). Responses to address weather-related risks can be either short or long term, ranging from specific practices to processing and/or product choices (Belliveau et al., 2006a, b). A risk-management strategy to handle one problem may inadvertently increase risk in another. For example, the grape pullout program in 1988 and the apple replant program from 1992 onwards have increased vulnerability to climate risks (*see* Section 4.3.2). Support programs, such as the Canadian Agriculture Income Stabilization Program, may be a disincentive for producers to take other adaptation measures to reduce risks (Belliveau et al., 2006a, b). In general, safety net programs are a good hedge against crop losses caused by weather but are less effective in sheltering farmers against losses caused by more subtle impacts on quality and by the longer term persistence of climate change.

## 3.5 TOURISM AND RECREATION

Tourism is BC's second largest economic sector next to forestry, generating approximately $5.8 billion in 2003 and $9.5 billion in 2004 (BC Ministry of Labour and Citizens' Services, 2005b; Tourism BC, 2005a). Tourism provides more than 117 500 jobs, approximately 7% of total provincial employment (Hallin, 2001; Tourism BC, 2005a). Although Vancouver and Victoria are major urban destinations, visitors are also drawn to BC's mountains and coastal regions. Many resource-based communities now view tourism as a means of economic restructuring after declines in the forestry and fishery sectors (Reed and Gill, 1997).

British Columbia's scenery, wilderness, wildlife viewing, and hunting and fishing opportunities provide for a burgeoning adventure and nature-based tourism industry. In 2001, nature-based tourism contributed $1.55 billion in revenues (including spin-off activities) and $783 million in provincial GDP (Tourism BC, 2005a, b). Most of this occurs at destination resorts and within BC's many parks and protected areas (*see* Section 3.6).

The effects of climate change on tourism destinations are already evident. In BC's drier southern interior, drought and forest fires during the summer of 2003 closed many major transportation routes and destroyed orchard and winery crops in the Okanagan and North Thompson valleys. Agri-tourism to wineries and orchards was impacted and regional hotel room revenues declined by 3% (BC Council of Tourism Associations, 2004). These areas and activities can expect increasing frequency of drought hazards in the future.

Projected rises in snowlines due to warming temperatures (Scott, 2003a, b, 2006a) will impact ski operations across the province. For example, the retreat of alpine glaciers that support off-season skiing will affect mountain resorts such as Whistler-Blackcomb. Inadequate snowfall reduces the number of suitable skiing days available to local resorts, such as Vancouver's Grouse, Seymour and Cypress mountains (Scott et al., 2005).

Tourism in coastal communities will be affected by sea-level rise and increased coastal erosion and flooding hazards (Craig-Smith et al., 2006), and associated impacts on transportation infrastructure, marina maintenance and dredging activities, boating safety, floatplane travel, vacation housing and resort infrastructure. Key impacts on coastal fisheries relevant for sport fishing are discussed in Section 3.2.

### *Adaptation*

Successful tourism operations are inherently dynamic and resilient to environmental and other changes. This adaptive capacity suggests that the sector is relatively well positioned to respond to climate change impacts (Scott et al., 2003). Adaptation measures typically involve short-term responses, such as marketing strategies aimed at changing tourist behaviour, or longer term planning to adjust to local climate change impacts. However, climate change is only one of many factors to which tourism operations must adapt. Other key factors include changing market competition, fluctuating currency values, and changing tourist demands, interests and demographics (Uysal, 1998). Adaptive measures, such as re-marketing, re-imaging and diversification of activities, are already happening. For instance, Tofino, a traditionally popular summer tourist destination on Vancouver Island's west coast, is now also attracting tourists for winter storm watching (Dewar, 2005).

A key adaptation strategy for weather-dependent tourism is to spread the risk by diversifying operations and reducing reliance on single-season activities. Ski resorts are adapting to recent climate change through snowmaking and introduction of activities that are not dependent upon snow (Scott et al., 2003; Scott, 2006b). Snowmaking is capital intensive and requires significant water resources that, in many regions, are already under stress. Larger, multi-resort corporations have a higher adaptive capacity than smaller operators, as they generally have greater access to capital to undertake adaptation and are less impacted by poor conditions at a single site. The longer, more predictable ski season that snowmaking can produce reduces business risks during the winter and further stimulates diversification. In turn, this encourages property and infrastructure investments throughout the year (Scott, 2006b). For example, the Whistler-Blackcomb resort has diversified itself into a multi-season resort that includes golfing, mountain biking and alpine hiking. Some of these activities use the same infrastructure used in the winter for skiing.

Other important adaptive measures include hazard risk reduction and comprehensive emergency management to deal with increased floods, landslides and avalanches associated with wetter and warmer fall-winter conditions.

## 3.6 PARKS AND PROTECTED AREAS

British Columbia has the highest biodiversity of any province and hosts some of Canada's most vulnerable and fragmented ecosystems. There are 859 protected areas in BC, accounting for more than 13% of the landscape (approx. 12.6 million hectares). Climate change impacts in Canada's national parks are only beginning to be considered, for example, through identification of key 'geoindicators' for monitoring changes (Welch, 2002, 2005). Impacts on ecosystem integrity from species migrations and major biome shifts, expected as a result of climate change, have yet to be considered (Scott and Lemieux, 2005). Compared to terrestrial areas, marine protected areas are under-represented, with less than 1% of BC's waters fully protected. Climate change impacts on sea-surface temperatures, species migrations and diversity, and ocean productivity have received little consideration in the planning and management of marine protected areas.

The ClimateBC program was used to simulate changes in temperature and precipitation, at a downscaled resolution of 1 km$^2$, within selected protected areas (Table 7; Hamann and Wang, 2005, Wang et al., 2006) to assess possible ecosystem responses. Such modelled results need to be considered in the context of past ecosystem dynamics, changes in disturbance regimes (fire, invasive species, pests), land management objectives and human demands on resources, to contribute to the development of adaptive management plans addressing multiple objectives.

Tourism, traditional Aboriginal resource use, park operations and research are the main human activities in BC's parks. Key climate change risks to be managed in the park system include 1) alpine and subalpine ecosystem decline and fragmentation due to increased temperatures (Scott and Suffling, 2000; Suffling and Scott, 2002); 2) increasing impacts from natural hazards (avalanches, wind storms, storm surges, droughts and landslides) as a result of increased frequency and/or magnitude of extreme weather, affecting visitor safety and maintenance of park infrastructure and services; and 3) species migration, extirpation and increasing exotic species competition, impacting harvest rights, biodiversity and population sustainability for both terrestrial and marine species. The most vulnerable protected areas are those subject to intense human activity and development pressures, such as those in the Greater Vancouver–lower mainland region, on southern Vancouver Island and in the Okanagan valley.

### *Adaptation*

Climate change represents a challenge to the fundamental goal of most protected areas, and requires that a dynamic perspective be applied to the concept of maintaining ecological integrity. Parks Canada has developed a list of possible responses to current and future climate change impacts, including enhancing connectivity to enable species migration, expanding some protected areas, limiting other stressors on ecosystems, and species relocation programs (Hannah et al., 2002; Welch, 2005). Similarly, conservation networks between protected areas in developed regions would help facilitate species movements and biodiversity conservation under a changing climate.

**TABLE 7:** Climate normals (1961–1990 averages) and forecasted values (2050) for selected British Columbia parks (average estimates generated on a 1 km grid using ClimateBC v2.0 software and the CGCM2 climate model with Intergovernmental Panel on Climate Change SRES A2 emissions scenario).

| | Elevation (m) | Mean annual temperature (°C) | | Mean warmest month (°C) | | Mean coldest month (°C) | | Mean annual precipitation (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Normal | 2050 | Normal | 2050 | Normal | 2050 | Normal | 2050 |
| **Tweedsmuir Provincial Park (PP)** | 1254 | 1.2 | 3.4 | 11.3 | 13.4 | -9.7 | -7.0 | 914 | 938 |
| **Wells Gray PP** | 1487 | 0.8 | 3.0 | 11.7 | 13.9 | -10.1 | -6.7 | 1203 | 1241 |
| **Spatsizi PP** | 1522 | -2.4 | 0.3 | 10.0 | 12.7 | -13.9 | -9.4 | 906 | 969 |
| **Garibaldi PP** | 1580 | 2.1 | 4.2 | 11.7 | 13.7 | -6.2 | -3.9 | 2745 | 2852 |
| **Granby PP** | 1759 | 1.6 | 3.9 | 12.8 | 15.0 | -8.6 | -5.9 | 966 | 973 |
| **Kootenay National Park (NP)** | 1830 | -0.1 | 2.4 | 11.6 | 13.9 | -12.1 | -8.3 | 1082 | 1099 |
| **Glacier NP** | 1829 | -0.5 | 1.8 | 10.7 | 12.9 | -11.3 | -7.8 | 1988 | 2057 |
| **Gulf Islands NP Reserve** | 84 | 9.7 | 11.8 | 16.2 | 18.3 | 3.8 | 5.9 | 798 | 842 |

| | Mean summer precipitation (mm) | | Mean annual snowfall (mm) | | Frost-free days | | Growing degree days (GDD; >5 °C) | | Day of year when GDD total 100 (budburst) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Normal | 2050 | Normal | 2050 | Normal | 2050 | Normal | 2050 | Normal | 2050 |
| **Tweedsmuir PP** | 253 | 246 | 493 | 416 | 124 | 158 | 682 | 1029 | N/A | 145 |
| **Wells Gray PP** | 456 | 457 | 616 | 540 | 126 | 159 | 703 | 1049 | 166 | 145 |
| **Spatsizi PP** | 406 | 424 | 477 | 467 | 103 | 138 | 423 | 737 | 179 | 155 |
| **Garibaldi PP** | 569 | 538 | 1402 | 1077 | 136 | 169 | 725 | 1047 | 169 | 152 |
| **Granby PP** | 407 | 383 | 445 | 361 | 135 | 169 | 815 | 1163 | 165 | 147 |
| **Kootenay NP** | 500 | 486 | 518 | 459 | 116 | 150 | 678 | 1040 | 166 | 144 |
| **Glacier NP** | 565 | 555 | 1230 | 1126 | 121 | 152 | 542 | 852 | N/A | 157 |
| **Gulf Islands NP Reserve** | 157 | 146 | 42 | 30 | 322 | 349 | 1957 | 2688 | 89 | 27 |

Monitoring and research on species and ecosystem responses remain important, as this helps to document impacts and inform adaptive planning and management approaches. Protected areas serve as 'benchmarks' for adaptive ecosystem management within larger landscapes subject to the additional pressures of resource extraction, agricultural use and urban development.

## 3.7 ENERGY

Discussions of climate change and energy typically focus on the links between energy production and greenhouse gas emissions. In British Columbia, where 89% of the province's electricity is hydro generated (BC Hydro, 2006), the energy sector is highly sensitive to the impacts of climate change on water resources (*see* Sections 2.4, 3.1 and 4.3.1). Research on climate change impacts and potential adaptive measures of the energy sector in BC is extremely limited. However, the following considerations are beginning to attract the attention of energy researchers and managers:

- Water shortages are already a risk for BC's hydroelectric resources. Storage reservoirs face reduced snow packs, declining glacier contributions and frequent drought, all of which tax the system's capacity to meet demands (BC Hydro, 2004).

- Electricity demand in BC by 2025 is expected to be 33 to 60% higher than in 2005 (BC Hydro, 2006). All new electricity generation measures, including coal-fired plants, are planned for zero net greenhouse gas emissions (BC Ministry of Energy, Mines and Petroleum Resources, 2007).
- Seasonal and longer term energy demands for buildings (e.g. increased summer cooling needs, lower heating requirements) will change across the province in response to changing climate. By 2010, new energy-efficient bulding standards are proposed for implementation (BC Ministry of Energy, Mines and Petroleum Resources, 2007).

British Columbia's main hydroelectric generation reservoirs on the Columbia and Peace rivers depend on water flows mainly from snow pack and/or glacial melt. Some smaller 'run-of-river' facilities have limited storage and require continuous flow. Studies of the impacts on water supply and hydroelectric generating vulnerabilities are ongoing in the Williston-Peace, Bridge River and Columbia River basins, and current climate variability is an important consideration in planning reservoir operations strategies (BC Ministry of Environment, 2004).

Substantial shifts in energy demand are also anticipated as a result of increasing temperatures, with heating energy demands decreasing and cooling energy demands increasing. Illustrative models developed by the Royal BC Museum (2005b), based on projected changes in cooling and heating degree days, suggest that domestic heating energy demand may decrease 28 to 55% and summer cooling demand may rise 150 to 350% by 2080 in the Vancouver region (Figures 8 and 9).

## *Adaptation*

BC Hydro aims to meet approximately 50% of increased electricity demands by 2020 through conservation and efficiency measures, including programs for consumers and the construction industry (BC Ministry of Energy, Mines and Petroleum Resources, 2007). Numerous programs exist that

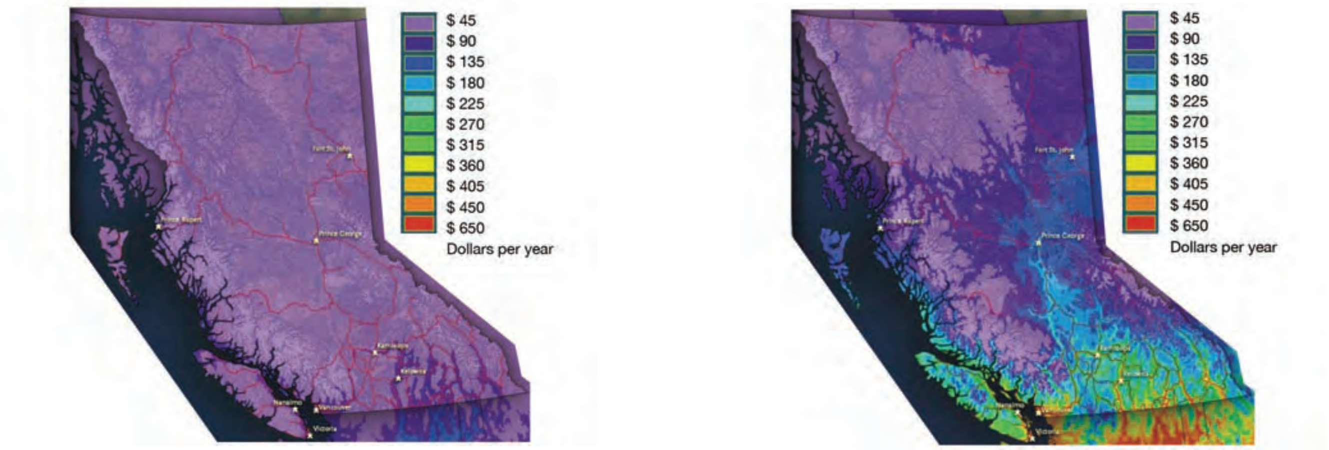


**FIGURE 8:** Summer cooling costs for a typical British Columbia house. The left panel shows baseline costs, and the right panel shows projected costs for 2080 based on a high change climate scenario (Royal BC Museum, 2005b)

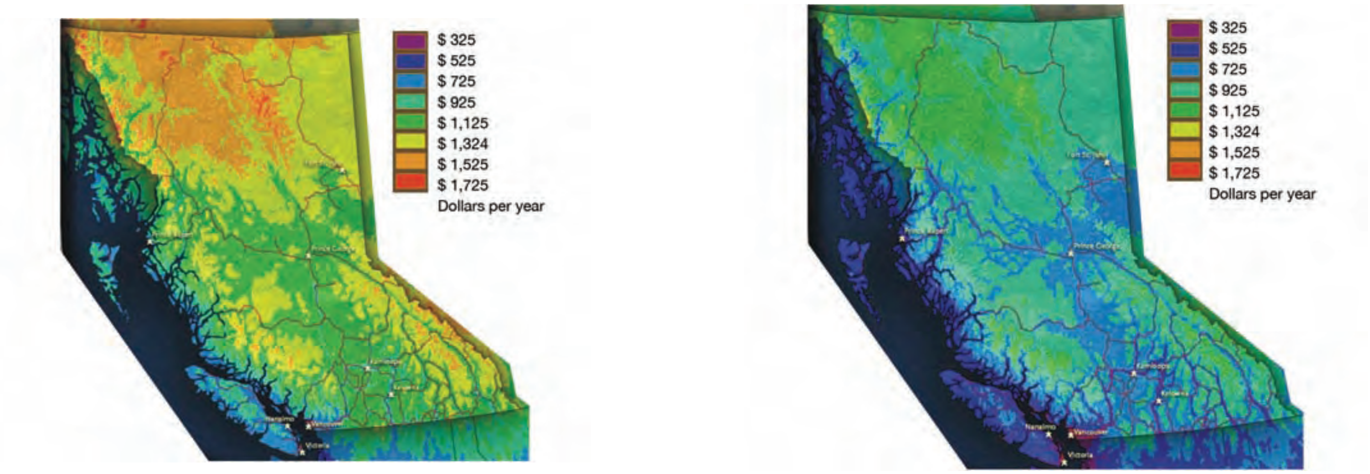


**FIGURE 9:** Winter heating costs for a typical British Columbia house. The left panel shows baseline costs, and the right panel shows projected costs for 2080 based on a high change climate scenario (Royal BC Museum, 2005b).

promote energy efficiency (e.g. BC Sustainable Energy Association, 2006; BC Ministry of Energy, Mines and Petroleum Resources, 2006; FortisBC, 2006; Natural Resources Canada, 2006). These and similar initiatives have both mitigative and adaptive benefits, in that they reduce greenhouse gas emissions and reduce demands on climate-sensitive sources of electricity.

Independent power producers, potentially including coal-fired generating plants, and efficiency improvements to existing hydroelectric plants will supply British Columbia's remaining future demands (BC Hydro, 2006). BC Hydro's (2006) Integrated Electricity Plan states that at least 50% of new power supply needs will come from renewable sources, including hydroelectricity, biomass and wind power. All new power generation facilities and coal-fired plants are planned for zero net greenhouse gas emissions (BC Ministry of Energy, Mines and Petroleum Resources, 2007).

Future energy demand forecasts and resource supply options must consider climate change impacts, as improved energy efficiency measures and building designs will only alleviate some of the expected increases in power demand. Improvements in stream-flow prediction modelling that consider changing climate represent a starting point in assessing supply vulnerabilities for hydroelectric power generation. Potential adaptation measures include expansion of reservoir systems to include supplemental 'pumped-storage' facilities, which store water above the reservoir to supply a generating station.

## 3.8 CRITICAL INFRASTRUCTURE

Critical infrastructure includes various technology networks, facilities, systems and services that are key to the well-being and operations of society (Public Safety and Emergency Preparedness Canada, 2006b). It involves a multitude of systems for energy and public utilities, health care, transportation, food supply, industry, communications and information technology, finance, safety and rescue, and defence. Impacts of recent extreme weather events demonstrate that vulnerabilities exist in these interconnected and interdependent systems. British Columbia's Emergency Response Management System (BC-ERMS; Public Safety and Emergency Preparedness Canada, 2006a) reports on, and aims to reduce the impacts of, environmental hazards, such as floods and wildfires. Critical infrastructure protection and planning, however, resides with a host of public agencies from all levels of government.

**TABLE 8:** Trends in emergency events in British Columbia (Whyte, 2006). The damage claims referred to in the table are 'eligible damages' that qualify under the Disaster Financial Assistance program (not inclusive of all damages that might have occurred), and represent both the federal and provincial share of costs.

| Parameter | 1990–2002 | 2003–2005 |
|---|---|---|
| Average number of threshold events[1] per year | 1 | 2 |
| Number of major Disaster Financial Assistance (DFA) events per year | 2–3 | 3–5 |
| Average DFA and response costs | $10 million | $43 million |
| Frequency of evacuations | Every 2–3 years | 2 times/year |
| Frequency of States of Emergency (SOE) | Rare | 1 provincial SOE and 10 local SOEs in 3 years |

[1] A threshold event is one where eligible costs reach $4 million.

In 2003–2005, British Columbia experienced a significant increase in the number of extreme weather events requiring widespread emergency responses, compared to the previous decade (Table 8). Such emergencies are managed through BC-ERMS when the impacts to a community or significant infrastructure are likely to overwhelm the response capacity of local authorities. The BC-ERMS organization recognizes the potential for increasing frequency and severity of such natural hazard risks as wildfires, flooding, drought, mass-wasting events and pest proliferation as a result of climate change. The system is both reactive, through financial claims support to communities, businesses and homeowners, and proactive, through support to local authorities and communities for hazard risk-reduction initiatives and education and awareness programs. The maximum support for individual damage claims has recently been tripled from $100 000 to $300 000 (Whyte, 2006). By increasing risk awareness and emergency preparedness, BC-ERMS also enhances adaptive capacity to address climate change adaptation.

### *Transportation*

Transportation and associated activities (e.g. warehousing, pipelines, sightseeing, couriers) are an important component of BC's economy, accounting for 6% of the provincial GDP and employing 6% of the workforce (more than 115 000 people) in 2004 (BC Ministry of Labour and Citizens' Services, 2005a). Road, rail, air and marine transport are all important components of the transportation system, providing critical links for other key economic sectors (e.g. forestry) to associated processing facilities and markets. More than 65 000 km of roads in BC carry more than 2 million passenger and service vehicles per year (Transport Canada, 2005). Almost 65% of the network is provincially owned, 32% is municipal and 3% is federal. In the area of marine transport, British Columbia has more than 135 public and private ports that facilitate 95% of international trade moving through the province (BC Ministry of Small Business and Economic Development and Ministry of Transportation, 2005). Goods shipped to and from the three main trading ports of Vancouver, Fraser Port and Prince Rupert are moved by rail (66%) and truck (33%), with shipping container traffic projected to triple from 2 to 6 million containers per year by 2020 (Greater Vancouver Transportation Authority, 2005).

Climate change impacts BC's transportation infrastructure in many ways. Increases in the frequency of some extreme weather events will increase maintenance and insurance costs, and expose the limitations of some current design standards. Wear on highways, although primarily a function of vehicle weight and traffic volume, is also impacted by climate conditions. For example, rising maintenance costs in Prince George are partly attributed to more frequent freeze-thaw events associated with recent warmer winters (Dyer, 2006). Climate change will also have positive impacts on transportation. For example, during the El Niño winter of 1997–1998, milder weather helped to significantly reduce motor vehicle accidents on BC roads (Environment Canada, 2003).

### *Utilities and Services*

Water supply and stormwater management systems in BC will continue to be impacted by changing climate and increasing development pressures. Key impacts to be considered include 1) decreased water supplies during summer and fall (*see* Sections 2.4 and 3.1); 2) supply-demand mismatches in reservoir systems that supply BC's major urban centres (*see* Section 4.4.1); 3) increased demands on drinking water and sewage treatment facilities in rapidly growing communities; and 4) increased loading of stormwater management systems as a result of more frequent and/or more intense extreme precipitation events (*see* Section 4.4.2).

Major pipeline infrastructure expansions are planned for the near future to move producible oil and natural gas from the northern territories and northeastern BC to international markets. The impacts of a changing climate in mountainous and permafrost regions of BC (e.g. permafrost melt, landslides, rockfalls) need to be considered in the planning, design and construction of pipeline infrastructure to avoid increased maintenance costs and, potentially, major repair and environmental rehabilitation efforts.

## 3.9 HEALTH

Vulnerability of human health is a function of interacting biological, environmental and socioeconomic factors (e.g. immunity, urban setting, income, access to health care services; Woodward et al., 2000). Climate change poses both direct and indirect health threats at the individual and population levels. Direct threats include increases in the number of injuries, illnesses and deaths related to poor air quality, natural hazards, extreme weather and heat. Indirect threats include exposure to air-, water- and vector-borne diseases and declines in ecosystem health (McMichael et al., 2003; Haines and Patz, 2004).

### *Heat Stress and Air Quality*

Heat stress is associated with thousands of deaths each year in Canada (Smoyer-Tomic et al., 2003). More frequent, intense and longer lasting heat waves associated with climate change are expected to produce significant heat-related impacts, including heat stroke, dehydration and cardiovascular-respiratory illness and mortality (McGeehin and Mirabelli, 2001). The impacts of recent heat waves elsewhere in the world demonstrate that vulnerable populations include seniors, children, the poor and those who are socially isolated (Klinenberg, 2002; Crabbe, 2003). Although heat stress may appear less threatening in BC compared to central Canada (*see* Chapters 5 and 6), much of the BC population is less acclimatized to temperatures above 30°C (Smoyer-Tomic et al., 2003). Large urban populations in the Greater Vancouver Region and the Okanagan valley are particularly vulnerable. Non-respiratory emergency room visits in Vancouver currently increase with high summer temperatures (Burnett et al., 2003) and are expected to increase further with an aging population.

Air pollution increases in urban areas already exposed to air-quality hazards, particularly Greater Vancouver, Prince George and the Okanagan valley, will also have significant health consequences. Airborne pollutants cause wheezing, asthma attacks and impaired lung function, and are associated with increased respiratory illness, stroke, heart attack and premature death, especially for the elderly and children (Brook, 1998; Burnett et al., 1998; Caulfield, 2000; Kondro, 2000; Van Eeden et al., 2001; Brauer et al., 2002, 2003). Expected increases in forest fire frequency associated with changing climate will increase exposures to fine particulate matter from wood smoke (cf. Dods and Copes, 2005). Fine particulate matter is linked to premature deaths, exacerbation of asthma, acute respiratory symptoms and chronic bronchitis, and decreased lung function, especially in children (Vedal, 1993).

Together, increasing heat stress and exposure to air pollution will increase illness, absenteeism, hospitalization and premature mortality. Already, the annual health burden of outdoor air pollution for BC is estimated at approximately $85 million (BC Ministry of Health, 2004).

### *Disease Exposure*

Diseases spread by water, vectors (e.g. animals, insects) and air are expected to increase as a result of climate change. Waterborne diseases are likely to increase in some areas of BC as a result of increased precipitation and flooding. Twenty-nine waterborne outbreaks have occurred in the province since the 1980s, due to parasites, bacteria and viruses in drinking water systems (Mullens, 1996; Wallis et al., 1996). Boil-water advisories are common. Three hundred and four were issued in August 2001 (BC Ministry of Health Planning and Ministry of Health Services, 2001). Extreme precipitation also contributes to elevated turbidity levels that reduce the effectiveness of drinking water disinfection systems. During November 2006, a boil-water advisory was issued by Greater Vancouver Regional District (GVRD) Medical Health officers that affected almost 1 million people for 12 days following an extreme rainfall that led to turbidity levels "unprecedented in recent years" (Greater Vancouver Regional District, 2006). First Nations communities are particularly vulnerable to water-quality advisories and currently experience more than the rest of Canada, due to poor infrastructure.

Climate change will enable many disease vectors, such as mosquitoes, ticks and rodents, to extend their range and thereby increase human exposure. For instance, the mosquito-borne West Nile virus, although not yet found in BC, is spreading due, in part, to changing climate, and may become one of North Americas' leading arboviral diseases (Morshed, 2003). Encephalitis and Lyme disease from ticks may expand in range with expected warmer winters, as observed in Europe in the 1990s (Lindgren et al., 2000).

In 1994, the first Canadian case of hantavirus pulmonary syndrome (HPS) was identified in BC (Stephen et al., 1994), and 50 more cases have emerged since then (BC Ministry of Health, 2005). In the United States, HPS epidemics are linked to rising rodent populations associated with climate and ecological changes (Wenzel, 1994; Engelthaler et al., 1999; Glass et al, 2000). Rodent breeding capacity is increased by mild winters (Mills et al., 1999; Drebot et al., 2000), conditions that are likely to be exacerbated by climate change.

*Cryptococcus gattii*, a tiny tropical yeast-like fungus, was identified on Vancouver Island in 1999 and more recently by the Vancouver Coastal and Fraser health regions (BC Centre for Disease Control, 2005). After inhalation, the fungus can cause serious illness and occasional death as it affects the lungs (pneumonia) and nervous system (meningitis). The changing distribution of this pathogen is linked to warming conditions (Kidd et al., 2004).

### *Food Security, and Public Safety and Well-being*

Climate change will affect access to food resources, particularly for rural and First Nation communities that rely on hunting, trapping, gathering and fishing for subsistence (O'Neil et al., 1997; Wheatley, 1998), thus exacerbating existing food insecurities (Willows, 2005).

Harmful algal blooms (HAB), or 'red tides', can flourish in summer months during extended warm periods. Increases in ocean surface temperature and storminess associated with climate change are stimulating HABs in British Columbia (Mudie et al., 2002). The most toxic red tides result from dinoflagellates, which cause illness or fatalities if large amounts of diseased shellfish are consumed (Mudie et al., 2002). Severe incidents of paralytic shellfish poisoning (PSP) have occurred on the BC coast (Taylor, 1993). In June 2006, most shellfish harvesting areas on Vancouver Island and the Gulf Islands were closed for several weeks. Rising ocean surface temperatures, in conjunction with the expansion of aquaculture in BC, can be expected to increase the incidence of economic and health impacts from harmful algal blooms.

Drinking water security is a major concern for water-stressed regions. Historically reliable water sources are not an assurance of continued supplies, as evidenced by the experience of Tofino, a resort town on the west coast of Vancouver Island. Tofino, accustomed to a very wet climate, experienced a major water shortage in the summer of 2006 due to increasing water demands and prolonged summer drought. The vulnerability of such communities to water shortages and related health impacts will likely increase due to climate change and increasing development pressures. The Drinking Water Protection Act (BC Statutes and Regulations, 2001) is intended to strengthen water protection in BC, but mentions little about adapting to climate change.

The increasing frequency of extreme weather events, such as flooding, storm surges, landslides and wildfires, constitutes a significant risk to public safety. Associated health impacts include injuries, increased disease exposure and mental health effects from financial and emotional stress (Ahern et al., 2005). Remote communities are particularly vulnerable, as they often depend on limited essential services and vulnerable critical infrastructure for the distribution of food, medical supplies and other essential goods and services (*see* Sections 3.8 and 4.1).

Finally, there are also strong relationships between ecosystem impacts, whether caused by climate or other factors, on economic livelihoods (i.e. jobs, incomes) and community and population health (Hertzman et al., 1994; Raphael, 2001). Research in BC's coastal communities clearly links deteriorating ecosystem, economic and social conditions with health consequences (Ommer, 2007).

### *Adaptation*

Awareness of climate change impacts on public health is growing, particularly in relation to increasing air pollution (BC Ministry of Health Services, 2004). Research networks on health are also growing (e.g. BC Environment and Occupational Health Research Network). There remains a need, however, for additional research on linkages between climate change and health impacts. In addition, co-ordination of disease surveillance with climate monitoring and environmental surveillance could provide important new insights.

Public health adaptation requires cross-sector approaches involving environmental managers, infrastructure developers, rural and urban planners, health care workers and administrators, public health educators, politicians and researchers. It also requires more information on prevention, protection and treatment of climate-related diseases (Parkinson and Butler, 2005) being made accessible to British Columbians.

# 4 TOWARDS ADAPTATION: CASE STUDIES IN BRITISH COLUMBIA

Vulnerability and adaptive capacity to climate change in British Columbia's communities are a product of social processes and environmental conditions and especially their interaction at the local or regional scale (Dolan and Walker, 2007). Key factors influencing adaptive capacity in BC include the following:

- The heavy reliance on natural resources, particularly forestry, exposes BC communities to environmental and market changes, and to combined climatic and non-climatic stresses (O'Brien and Leichenko, 2000).
- Governance structures, which regulate how ecosystems can be used and accessed by people, mediate both the social and economic use of natural resources. Few existing structures explicitly consider climate change impacts; fewer still have implemented adaptation-specific policy changes.
- Diverse sociocultural values and competing socioeconomic interests underlie debates over how best to plan and protect resources and the environment. Climate change makes the process of reaching effective compromise more complex and the outcomes more difficult to predict.

The case studies presented in this section highlight how these factors and other aspects of a community, region or economic activity influence its capacity to adapt to climate change. In general, adaptive communities require resilient social networks, services, governance, infrastructure and economic activities that can withstand a variety of socioeconomic and environmental changes (e.g. Dolan and Walker, 2007; Young, 2006b; Ommer, 2007; Page et al., 2007; Enns et al., in press). Adaptive capacity can be enhanced, or constrained, by the nature and structure of decision-making relationships and planning policy. Increased stakeholder involvement in BC's sociopolitical landscape, at both local and regional scales (Hoberg, 1996; Seely et al., 2004), has enhanced incorporation of local values and interests into land-use planning. For instance, conflict over logging practices in old-growth forests in the 1990s (Stanbury, 2000; Cashore, 2001) led to the development of the multi-stakeholder Land and Resource Management Planning (LRMP) process (BC Ministry of Agriculture and Lands, 1993), which is typically enacted at the local to regional scale. The LRMP process has had some success in reconciling conflicting positions and contentious land and resource disputes (Frame et al., 2004), although it has not yet integrated potential climate change impacts and adaptation into its mandate (Hagerman and Dowlatabadi, 2006).

The effectiveness of governance, from local to higher levels, is another factor influencing adaptive capacity. At the local level, community planning is a key mechanism for stakeholders in BC to consider and incorporate the effects of climate change. Planning is guided by the BC Municipal Act and other policy instruments, including Official Community Plans (OCPs), local zoning and building codes, and the provincial Agricultural Land Reserve (ALR). Currently, few regional decision-making processes, policies and institutions explicitly consider the potential impacts of climate change. Regional planning districts, water districts and other 'improvement districts' are mid-level jurisdictions in BC that will play a critical role in preparing for and managing some of the expected impacts of climate change (Jakob et al., 2003), such as for water supply and stormwater management (*see* Section 4.4; Burton et al., 2005).

At the provincial level, the BC Government released the report *Weather, Climate and the Future: BC's Plan* (BC Ministry of Environment, 2004), which discusses greenhouse gas mitigation and adaptation actions. The BC Ministry of Forests and Range (MFR) has also taken a proactive approach to integrating climate change considerations into medium- and long-term regional and resource planning procedures (BC Ministry of Forests and Range, 2006; *see* Section 4.2.2). The Ministry of

Community Services, which provides funding for community infrastructure, is now increasingly considering climate change in reviewing proposals from local authorities (B. Kangasniemi, BC Ministry of Environment, pers. comm., 2007).

Finally, there are striking differences between urban and rural communities in BC in terms of local policies, growth patterns, planning issues and social attitudes. Climate change impacts and adaptation issues need to be seen as relevant to local concerns within communities' planning and risk management responsibilities. Issues such as water management in the Okanagan basin, sea-level rise in coastal communities and the impacts of the mountain pine beetle in BC's interior forest-based communities are examples that illustrate how impacts and steps toward adaptation are being experienced in BC. Although explicit integration of climate change considerations is relatively rare, these case studies provide perspectives on steps being taken towards adaptation to a variety of social, economic and environmental stressors.

## 4.1 COASTAL COMMUNITIES: VULNERABILITIES AND ADAPTATION TO SEA-LEVEL RISE

Climate change affects British Columbia's coastal communities through the gradual effects of accelerated sea-level rise and the more immediate impacts of extreme events, including increased storm-surge flooding, accelerated coastal erosion, contamination of coastal aquifers and various ecological changes. Such biophysical changes create risks of land loss, coastal infrastructure damage, coastal resource changes and shifts in related economic, social and cultural values (Klein and Nicholls, 1999). Climate change impacts are, and will continue to be, unevenly distributed among coastal communities due to differing local exposures and vulnerabilities (Clark et al., 1998; Dolan and Walker, 2007). These impacts are superimposed on non-climatic issues, including First Nations land claims, decline or collapse of key natural resource industries, economic restructuring, and the loss or reduction of social support and government services (Ommer, 2007; Sydneysmith et al, 2007).

A Canada-wide assessment of the impacts of sea-level rise (Shaw et al., 1998) defines 'coastal sensitivity' as the degree to which sea-level rise will initiate or accelerate physical changes to the coast. Most of BC's coast is steep and rocky, and therefore has a moderate to low sensitivity. Exceptions include the northeastern coast of Graham Island, Haida Gwaii (Queen Charlotte Islands) and the Roberts Bank–Fraser Delta region in Greater Vancouver. These areas are ranked amongst Canada's most sensitive coastlines to climate change. However, this sensitivity analysis does not fully assess vulnerability to climate change, as it does not consider adaptive capacity (cf. Luitzen et al., 1992; Smit et al., 2001). Adaptive capacity is determined by socioeconomic setting (access to economic resources, political and social capital, and coastal planning policy) and local experiences with environmental hazards and socioeconomic changes (Dolan and Walker, 2007). The two cases presented here highlight communities experiencing similar physical impacts in very different socioeconomic settings. Key vulnerabilities, adaptive capacities and steps toward adaptation are discussed.

### 4.1.1 Northeastern Graham Island, Haida Gwaii (Queen Charlotte Islands)

Graham Island is the largest, northernmost island in the Queen Charlotte archipelago (Haida Gwaii). Relative sea level is currently rising at 1.6 mm/a and extreme annual sea levels at 3.4 mm/a (Abeysirigunawardena and Walker, in press). The shores of northeastern Graham Island consist mostly of highly erodible dune and bluff sediments. This, combined with high tides, energetic wave climate, frequent storm surges and high winds, creates a highly dynamic coastline with actively shifting beaches (Walker and Barrie, 2006). Water level and coastal erosion trends are strongly influenced by ENSO and PDO (Storlazzi et al., 2000; Dingler and Reiss, 2001; Allan and Komar, 2002; *see* Section 2.1). During El Niño 1997–1998, sea level rose 0.4 m and caused 12 m of local erosion along this shoreline (Barrie and Conway, 2002), and extreme water levels have increased significantly since the positive PDO shift of 1976 (Abeysirigunawardena and Walker, in press).

Climate change is one of many stressors affecting communities in Haida Gwaii. The local forest industry has experienced turbulent international timber markets, increasing costs of access, and changes in forest management, technology and protection, leading to declines in on-island processing and jobs. The local fishing industry has experienced changing populations of salmon, herring and clams, as well as restricted fishing privileges. In addition, closure of Canadian Forces Base Masset led to the out-migration of hundreds of people, resulting in further job losses and socioeconomic restructuring.

#### *Adaptive Capacity*

Dolan and Walker (2007) presented an integrated, human-environmental research framework to assess climate change–related risks and vulnerabilities of communities on northeastern Graham Island. Resulting research by Walker et al. (2007) involved assessment of climate change trends, impacts and sensitivities (Walker and Barrie, 2007; Walker et al., 2007; Abeysirigunawardena and Walker, in press), and a sociocultural assessment by Conner (2005) used a 'participatory approach', incorporating local knowledge, perceptions and experiences to define attributes of adaptive capacity and identify key vulnerabilities. This study identified many attributes capable of strengthening adaptive capacity (Table 9) that may not be readily captured by the typical attributes of vulnerability, such as wealth. In Haida Gwaii, a historically high dependence on natural resources for jobs, below-average household incomes, high unemployment rates and income instability suggest a high vulnerability and low adaptive capacity. At the household level, however, socioeconomic resilience is enhanced by income diversification (multiple jobs, arts and crafts, tourism) and food gathering and stockpiling. This suggests a higher adaptive capacity to the risks of climate change than would be interpreted from income and employment statistics alone.

Access to technology, information and skills, critical infrastructure and essential services are other community-level factors of adaptive capacity (Goklany, 1995; Barnett, 2001). Most critical infrastructure and transportation services in Haida Gwaii are highly vulnerable to coastal storm damage. Frequent power outages, interrupted ferry and flight service, short-term grocery and supply shortages, occasional highway closures and wind damage are commonplace. Most communication services are available in Haida Gwaii, including high-speed Internet and cellular phone coverage. Community messages are broadcast on local TV, in flyers and in the local newspaper. A tsunami evacuation plan exists, but is not well recognized, despite established protocols and tests. Recognition of the need to adapt, knowledge about available options, capacity to assess them and ability to implement the most appropriate options are all dependent on the availability of credible information and appropriate skills (Fankhauser and Tol, 1997).

Risk perception, awareness and preparedness are also attributes of adaptive capacity (Burton et al., 1978; Barnett, 2001; Smit et al, 2001; Dolan and Walker, 2007). Risk perception depends on knowledge and past experience with hazards, such that greater awareness comes with greater knowledge and experience (Hutton and Haque, 2004; Degg and Homan, 2005). Despite generally low levels of formal education in Haida Gwaii, high informal education, local and traditional environmental knowledge, and a diverse informal skill set (e.g. hunting, gathering and backcountry skills) result in a high general risk awareness and preparedness for natural hazards. However, many residents do not perceive risks from longer term climate change *per se*, compared to those associated with extreme events such as storms, coastal erosion or tsunami.

Social capital, which includes relationships, networks and infrastructure that support the flow of information and skills toward shared values, goals and collective action (Coleman, 1988; Tobin, 1999), is another important determinant of adaptive capacity. Communities with greater social capital may

**TABLE 9:** Local attributes of vulnerability and adaptive capacity to climate change impacts in Haida Gwaii (*modified from* Walker et al., 2007).

| Factors that increase vulnerability[1] | Factors that enhance adaptive capacity[2] |
|---|---|
| • Geographic isolation<br>• High exposure to climate variability hazards and sea-level rise | • Strong attachment to Haida Gwaii<br>• Connectedness with nature<br>• Frontier mentality<br>• Experience with environmental changes and hazards |
| • Low formal education levels (cf. Holman and Nicol, 2001) | • High informal education, local knowledge, traditional ecological knowledge<br>• Haida culture and rediscovery<br>• Diverse skills (hunting, gathering, etc.) |
| • Limited provision of essential services (health care, social services, education)<br>• Generational health impacts (alcoholism, abuse, apathy) | • Strong community cohesion and support networks (e.g. family ties, volunteer groups)<br>• Increasing volunteerism and local involvement in essential services (e.g. women's shelters, community health programs) |
| • Poor dissemination and awareness of emergency plans | • Established evacuation protocols and tests<br>• Increased communication between communities |
| • Frequent power outages<br>• Short-term food shortages | • High coping capacity with power shortages<br>• Local food gathering and hunting<br>• Food stockpiling and preserving |
| • High unemployment<br>• Dependence on unstable natural resource sector<br>• Low, long-term economic stability | • Household income diversification/subsidization (multiple jobs, arts, food gathering, tourism)<br>• Seasonal jobs (fisheries/crabbing, mushrooms, tourism/charters)<br>• Increased resilience to economic hardships |
| • Lacking official land-resource and/or land-use management plans[3] | • Ongoing development of integrated LRMP incorporating Haida Land Use Vision and resident values |
| • Local, regional and federal political tensions | • Increasing local involvement and Haida governance in decision-making process |

[1] as defined in existing scholarship (*see* Chapter 2).

[2] as found in Conner (2005).

[3] in January 2006, a recommendation plan was forwarded to the BC Integrated Land Management Bureau (<http://ilmbwww.gov.bc.ca/lup/lrmp/coast/qci/> [accessed August 20, 2007]); as of November 2006, no formal land use plan existed.

deal more effectively with hazards and the impacts of climate change (Buckland and Rahman, 1999). In Haida Gwaii, high social capital is suggested by strong community cohesion, numerous support networks, community activism and increasing local involvement in community services.

Institutions and governance also influence adaptive capacity. Historical conflict between community groups and orders of government on forestry and fishing, provision of services and local control in decision-making makes for a complex sociopolitical environment in Haida Gwaii. Longstanding negotiations between community groups, the Haida Nation and the BC government have yet to establish a Land Resource Management Plan (LRMP) for Haida Gwaii (Haida Gwaii–Queen Charlotte Islands Land Use Planning Process Team, 2006). An LRMP will be critical in determining future planning in Haida Gwaii; however, climate change considerations, such as coastal setbacks and limiting development on eroding coasts, are not part of the current report's recommendations.

### *Impacts and Adaptation*

Projected future impacts associated with changing climate include increasing coastal erosion, rising storm-surge damage and flooding, more frequent disruptions to critical transportation services, likely loss of coastal sections of Highway 16, rising costs of infrastructure maintenance, changes to coastal habitat and species abundance (crabs, clams) that will affect both commercial and sport fishing, and changes in the form and ecology of Rose Spit, an ecological reserve and Haida spiritual site.

Walker et al. (2007) have provided several adaptation considerations that build on existing community strengths and locally defined vulnerabilities. Adaptive planning is needed to reduce the vulnerability of exposed critical infrastructure, including coastal roads, low-lying buildings and airports, power-communication transmission lines and essential services. Possible initial actions include continued protection of vulnerable coastal stretches of Highway 16 and upgrades to existing logging roads for an alternate inland route. Consideration of coastal setbacks and land-use rezoning along eroding and flood-prone coastal areas are still needed. Economic development and renewal initiatives in tourism, arts, culture and resource stewardship will continue to diversify the local economy, enhancing community resilience. Enhancement of existing cultural, socioeconomic and political strengths will also improve overall adaptive capacity of Haida Gwaii communities to longer term climate change.

## 4.1.2 Roberts Bank, Greater Vancouver Regional District

The Roberts Bank tidal flats are located on the seaward edge of the Fraser River delta, bordering the Corporation of Delta and the Tsawwassen First Nation (TFN). The Corporation of Delta is a mixed urban and rural community that forms part of the Greater Vancouver Regional District. Delta and TFN are protected from river and storm-surge flooding by dykes along the river and shoreline. The tidal flats provide an important habitat for both birds and fish. Thousands of waterfowl, shorebirds and gulls use the tidal flats (Vermeer et al., 1994). Extensive beds of native eelgrass (*Zostera marina*) provide important spawning habitat for Pacific herring and feeding grounds for juvenile chinook and coho salmon (Levings and Goda, 1991).

The issue of assessing rising sea level and changing storm impacts on the Roberts Bank tidal flats involves complex stakeholder values and interactions (Hill et al., 2004). Two major causeways cross the southern end of Roberts Bank: a Vancouver Port Authority (VPA) structure providing access to the Delta Port shipping terminal and a BC Ferries Corporation structure serving a major ferry terminal. Both causeways were constructed in the 1950s, with little consultation with the communities, causing longstanding grievances and tensions. Stakeholder interviews identified key issues and positions around land and resource management on Roberts Bank. This information was used to design a workshop deliberation of potential climate change concerns, unhindered by historical grievances. Key concerns identified at the workshop included the integrity of infrastructure (dykes, causeways and port facilities), increased flood risk, loss of fresh water for irrigation during the summer, and loss of fish and bird habitat.

### *Impacts and Adaptation*

The main biophysical impacts of sea-level rise on the tidal flat environment are summarized in Table 10 (Hill, in press). The projected range of net relative sea-level rise for Roberts Bank is 0.23 to 1.02 m by 2100, based on Intergovernmental Panel on Climate Change (2001) projections of global sea-level rise, the historical rate of relative sea-level rise from tide-gauge data, and new ground subsidence data. Land subsidence in the Delta region accounts for 0.2 to 0.3 m of this relative rise (Mazzotti et al., 2006).

The tidal flats are characterized by different ecological zones supporting distinct habitats. These zones tend to migrate inland in response to rising sea levels. However, the presence of dykes impedes natural shoreline migration with sea-level rise, effectively 'squeezing' these zones against the dykes (Clague and Bornhold, 1980; Hughes, 2004). As sea level rises, wave motions presently attenuated by friction over the shallow delta surface will increase in amplitude, resulting in increased sediment transport and potential erosion of the marsh. This will be exacerbated greatly if the frequency of intense storms increases. Although uncertainties exist regarding marsh accretion and future sediment transport rates, it is expected that the mud-flat area will decrease significantly over the next century. These changes are likely to have a negative impact on certain bird populations (Hill, in press), as the marshes and mud flats are critical feeding habitat for migratory birds, such as the western sandpiper (Elner et al., 2005). Sea-level rise, as well as development pressures, will likely favour continued expansion of eelgrass beds, thus favouring fish habitat and bird species that feed on them, such as heron.

An immediate outcome of the Roberts Bank study (Hill, in press) is, as stated by the mayor of the Corporation of Delta, to make climate change and its effects on Delta a priority in the coming three years. A survey of municipal officials, including scientists, engineers and planners, demonstrates a high level of concern about the effects of climate change. Key concerns include the implications of sea-level rise and storm surges for protection of critical infrastructure and the natural environment. The effects of rising sea level are now being considered in a re-evaluation of dyke design by Delta, and in the development of an adaptive management plan for the Delta Port expansion project. A preliminary set of climate change impact indicators (Gregory et al., 2006), including biophysical (e.g. shoreline erosion, sedimentation), ecological (e.g. critical habitat area), socioeconomic (e.g. agricultural revenue), infrastructure (e.g. dyke integrity) and cultural (e.g. area of traditional land use), will provide a basis for future adaptive planning.

### 4.1.3 Summary and Lessons Learned

The Haida Gwaii study highlights aspects of remote coastal communities facing climate change and sea-level rise. Findings include the following:

- Remote communities and residents possess many resilient socioeconomic and sociocultural attributes that enhance their adaptive capacity to climate change risks in an otherwise exposed environment.

**TABLE 10:** Summary of biophysical impacts caused by rising relative sea level on Roberts Bank (*from* Hill, in press).

| Element | Effect | Impact | Confidence level |
|---|---|---|---|
| Global sea-level rise | 0.08–0.88 m by 2100 (Intergovernmental Panel on Climate Change, 2001) | | High |
| Land subsidence | 2–3 mm/year in the Fraser River delta | | High |
| Net relative sea level rise | Median values using 2 mm/yr subsidence:<br>2030: 0.17 m 2050: 0.27 m 2100: 0.62 m | | High |
| River flood frequency | Flood return periods will decrease due to rising base (sea) level, leading to higher risk | Negative | High |
| Marsh | Erosion of marsh due to coastal squeeze and increased wave attack; mitigated by natural marsh accretion up to a threshold rate | Negative | • Moderate confidence that the marsh will be stressed<br>• Low to moderate confidence that drastic changes will not occur before 2050<br>• Low to moderate confidence that the marsh will decline more rapidly after 2050 |
| Mud flat | Projected 45–63% reduction in area due to coastal squeeze; mitigated by some sedimentation over present marsh area; may be exacerbated by increased storminess and wave action | Negative | Low |
| Eelgrass | High modern expansion rates suggest eelgrass will migrate landward with changes in water depth | None | Moderate to high |
| Biofilm | Area likely to decrease with reduction in mud flat; higher wave energy may coarsen sediment and reduce productivity | Negative | Low |
| Predation of shorebirds | Likely to increase due to landward migration of optimum feeding grounds into range of predatory raptors (Butler, 1999). | Negative | Low |

- Community responses to past social, cultural and/or economic changes provide key information on elements of adaptive capacity to climate change (e.g. social capital, community cohesion).
- Despite inherent resiliencies, adaptive capacity to long-term impacts is challenged by 1) direct exposure to coastal storms and sea-level rise; 2) dependence on vulnerable critical infrastructure and limited essential services; 3) limited economic resources to cope with continued and increasing impacts; and 4) limited land-use development plans that typically do not consider climate change.

In the urbanized, complex multi-stakeholder situation represented in the Roberts Bank study, key findings include the following:

- Careful design of the stakeholder process is required to alleviate pre-existing conflicts and enable focused discussion on climate change issues.
- An analytical-deliberative process is required, whereby technical analysis informs deliberations that, in turn, refine understanding of overall risks (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, 1996), thus providing a mechanism for moving towards adaptation. This process needs to be iterative to allow technical experts and stakeholders to converge on a common understanding of key vulnerabilities and adaptation options.
- In coastal environments with considerable human interventions, climate change is superimposed on a variety of other biophysical changes. As such, climate change impacts must be assessed as part of a broader suite of cumulative environmental impacts occurring at a site.

Common findings from these studies relevant to other Canadian coastal communities include the following:

- Climate change is only one of many risks, changes and challenges facing coastal communities. This stresses the need to understand past community responses (e.g. social and economic restructuring, coastal development and infrastructure measures), in order to plan for future changes. Interventions in the coastal zone benefit from cumulative impacts assessments and integrated coastal zone management (ICZM) planning. Jurisdictional issues and historical conflicts can present key barriers to ICZM implementation.
- Community involvement is key to obtaining locally relevant results for adaptive planning. Reasonable time frames of 5 to 10 years are required to properly engage community stakeholders and develop feasible adaptation measures.
- The timelines required for community planning that incorporates consideration of climate change are long compared to most community planning processes in British Columbia. Rates of sea-level rise are initially slow but are likely to accelerate with time. Climate change risks (e.g. erosion, groundwater contamination, storm flooding, increasing transportation and infrastructure costs) are insidious and may occur sporadically. Thus, communities are faced with more complex risk analysis and high levels of uncertainty in the planning of infrastructure and land use. Furthermore, the process of adaptation evolves through time from early actions and monitoring of key indicators toward longer term planning strategies.

## 4.2 CENTRAL AND NORTHERN BRITISH COLUMBIA: MOUNTAIN PINE BEETLE AND FOREST-BASED COMMUNITIES

The communities and landscape of central and northern British Columbia epitomize the historical role of forestry in the province's development. Today, forestry management practices of the past have collided with contemporary climate conditions to produce a dramatic example of the impact of changing climate in Canada. This case study looks at the causes and consequences of the current outbreak of mountain pine beetle, how one forest-dependent community is attempting to understand its own vulnerability, and at a recent initiative of the provincial Ministry of Forests and Range that is taking a proactive approach to incorporating climate change impacts and adaptation into long-range forest resource planning and management.

### 4.2.1 Mountain Pine Beetle

The mountain pine beetle (MPB) is a native insect that occurs from northern Mexico to central British Columbia. It feeds on the succulent tissues beneath the bark of most pine species in its range (Furniss and Schenk, 1969). Although MPB is normally innocuous, populations periodically erupt into outbreaks that kill millions of trees over large areas (Taylor et al., 2006).

Mountain pine beetle outbreaks have occurred in BC several times during the twentieth century, but the area affected by the present outbreak is nearly 10 times greater than any previously recorded. In 2007, MPB infestations were recorded over 9.2 million ha of pine forests (BC Ministry of Forests and Range, 2007). For a MPB outbreak to occur, two main conditions must be satisfied. First, there must be an abundance of large, mature pine trees. As a result of fire suppression and historical factors, there was over three times the amount of mature pine in BC at the start of the current outbreak compared with 100 years ago (Taylor and Carroll, 2004). Second, there must be several years of favourable weather for beetle survival: specifically, warm summers for beetle reproduction and mild winters that allow their offspring to survive (Safranyik and Carroll, 2006). The climate in central BC during recent decades has been highly suitable for beetle survival, most notably in the lack of sustained cold conditions in winter (Carroll et al., 2004). The result has been the largest outbreak of mountain pine beetle in history.

In addition to the unprecedented size of this outbreak, the range of MPB is expanding into formerly unsuitable habitats, especially toward the north and east (Carroll et al., 2004). The present range is not restricted by the availability of suitable host trees, as pine forests extend north into the Yukon and the Northwest Territories, and east across the continent as part of the boreal forest. Instead, the potential for beetles to expand north and east has been limited by climate (Safranyik et al., 1975). Modelling indicates that climate conditions favourable to MPB have recently improved over large portions of western Canada (Figure 10), increasing the amount of climatically optimal habitat by more than 75% (Carroll et al., 2004). Climate change scenarios discussed by Flato et al. (2000) suggest continued expansion of favourable conditions for MPB eastward into Alberta and north into the boreal forest.

The unprecedented tree mortality associated with the current MPB epidemic significantly impacts forest hydrology (Figure 11; Hélie et al., 2005). The current and projected MPB infestation in BC will kill enough trees to cause greater exposure of soils to precipitation, potentially deeper snow accumulation and earlier melt, thereby increasing the risk of flooding. Such modifications to the hydrological cycle may account for observed changes in annual water yields and peak flows, and increased base flows/low flows in watersheds affected by MPB (Forest Practices Board of BC, 2007; cf. Cheng, 1989). More recently, other regions in BC have reported the occurrence of higher water tables (e.g. Vanderhoof Forest District) in MPB-affected areas (BC Ministry of Forests, 2005). The City of Prince George is also concerned about the potential for a heightened risk of flooding in low-lying parts of the city due to anticipated rises in the levels of the Nechako and Fraser rivers, especially during spring runoff (Dyer, 2006).

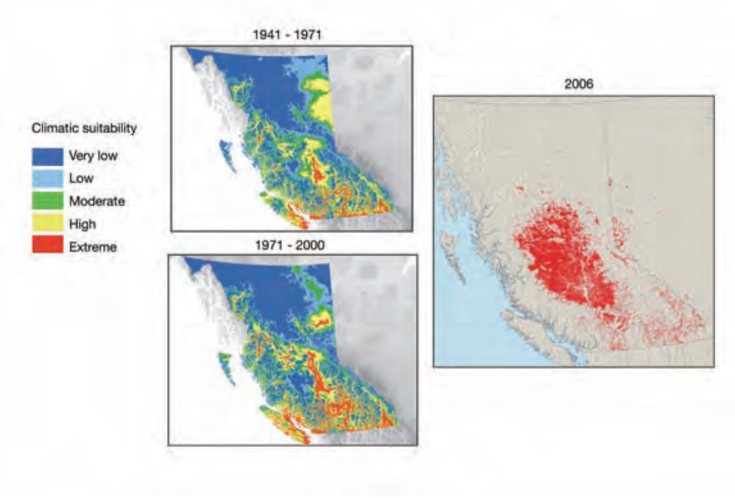


**FIGURE 10:** Left: Historical distributions of climatically suitable habitats for the mountain pine beetle (MPB) in British Columbia (*adapted from* Carroll et al., 2004). Areas with 'very low' suitability are unsuitable for MPB, where as 'extreme' areas are those considered climatically optimal. Right: Total area affected by mountain pine beetle in British Columbia in 2006 (Natural Resources Canada, 2007).

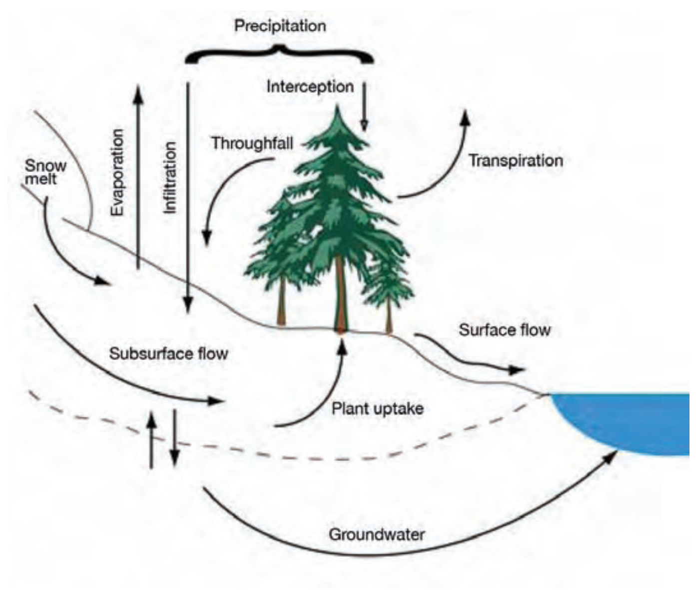


**FIGURE 11:** Forest hydrological cycle (*adapted from* Hélie et al., 2005).

The magnitude of hydrological impacts resulting from an MPB infestation depends on the extent and location within the watershed, as well as the geography of the watershed. Although these impacts will decrease as affected areas recover, higher flows could persist, at a decreasing rate, for as long as 60 to 70 years (Troendle and Nankervis, 2000). Some evidence suggests that harvesting MPB infested trees could advance the timing of hydrological recovery, as compared to a worst case scenario for natural regeneration (Dobson Engineering Ltd., 2004). Better understanding of the impacts of MPB and related harvesting on the hydrology of forested watersheds in BC is needed to determine appropriate levels of intervention and guide broader adaptation measures..

### 4.2.2 Vulnerability of Forest-Based Communities

The implications of changes in forest resources for residents of Vanderhoof and its surrounding region in north-central British Columbia exemplifies the challenges facing close to 110 forest-dependent communities in British Columbia. Although these communities face the same general impacts associated with climate change as other communities in BC, there are additional factors affecting their vulnerability. First, their economic dependence on extraction and processing of forest resources means that the local economy is highly sensitive to climate-induced changes in resource availability (Davidson et al., 2003). This economic exposure is magnified by the fact that climate change may lead to relative increases in the supply of timber and forest products from other nations, resulting in increased competitive pressures on the BC forest industry (Perez-Garcia et al., 2002; Sohngen and Sedjo, 2005). Second, many forest-based communities are relatively small and remote, with undiversified economies and specialized labour forces, limiting their capacity to adapt to climate change. Third, as the incidence and severity of wildfires are projected to increase as a result of climate change (Flannigan et al., 2005), forest-based communities will face increased risk of property loss, evacuation and deterioration in air quality due to increased fire activity (Davidson et al., 2003). Fourth, forest management and large-scale forest-processing facilities represent long-term investments that are difficult to reverse. Forestry decision-makers face long investment periods, dynamic risk and uncertainty that increase relative to the length of the forecast periods (Davidson et al., 2003). These factors underscore the importance of risk management in forestry and forest-based communities as an adaptation to climate change (Ohlson et al., 2005).

Vanderhoof has a population of 4400 with strong economic and social ties to the surrounding forest land base. The forest sector accounts for about 63% of the economic base of the community. The most immediate effect of changing climate on Vanderhoof is the current mountain pine beetle epidemic. The outbreak is having, and will continue to have, significant impacts on resource supply and local production of forest products. Prior to the MPB outbreak, the historical allowable harvest rate in the Vanderhoof Forest District was around 2 million m$^3$ per year, whereas the current annual harvest target is 6.5 million m$^3$ (Pederson, 2004). This increase has been implemented to utilize beetle-killed timber. Once the MPB has subsided (i.e. within about 10 years), the annual harvest level is projected to drop to between 1.25 and 1.75 million m$^3$ (Pederson, 2004). Thus, the Vanderhoof economy will experience significant volatility over a short time period. The challenge for Vanderhoof will be to manage this transition by ensuring that reductions in natural capital caused by the mountain pine beetle are offset by increases in other forms of useable capital (human-made capital, new forest or alternative land uses), to ensure that the long-term economic viability of the region can be maintained (cf. Pezzy 1989; Solow 1991).

Residents of Vanderhoof also have a strong cultural and psychological connection to their surrounding forest landscape, and are very concerned about the long-term implications of environmental changes for the community and future generations (Frenkel, 2005). The Canadian Forest Service is developing methods to simulate the long-term effects of climate change on forests at scales most relevant to communities. These methods have been applied to a 40 000 km$^2$ study area around Vanderhoof, to simulate future distributions of forest cover type in the year 2100 under two different climate futures (Table 11, Figure 12). Both simulations indicate significant changes in forest composition and provide general indications of potential changes over the next 100 years. The long-term impacts of climate change in terms of the nature and magnitude of forest ecosystem effects are not necessarily catastrophic — although the composition of the forest will change, forest cover will continue to exist under all future climate scenarios considered.

The Vanderhoof case study highlights that information on the magnitude and timing of impacts at locally relevant scales is required to facilitate consideration of adaptation. The experience of Vanderhoof also shows that the goal of managing a single resource in a sustainable manner may be difficult to achieve at a community level. Instead, reduction in one form of capital, in this case forests, may need to be offset by increases in other forms of capital, such as more land in agriculture or investment in new industries.

**TABLE 11:** Approximate areas in each of the simulated vegetation types, as a percentage of total area, in the Vanderhoof study area, British Columbia (*Source:* D. Price, Natural Resources Canada).

| Vegetation/forest type | Present-day (ca. 2000) | HadCM3-B2 (ca. 2100) | CSIRO2-A2 (ca. 2100) |
|---|---|---|---|
| Temperate softwood | 46 | 24 | 6 |
| Temperate hardwood | <1 | 0 | 10 |
| Boreal softwood | 54 | 75 | 26 |
| Boreal hardwood | 0 | 0 | 14 |
| Temperate mixed | <1 | 1 | 33 |
| Boreal mixed | 0 | 0 | 11 |
| Conifer-grassland mixed | 0 | <1 | 0 |

### 4.2.3 British Columbia's Climate Change Task Team and Future Forest Ecosystems Initiative

Climate change will play a major role in shaping the composition and use of forests in British Columbia. In recognition of this fact, the British Columbia Ministry of Forests

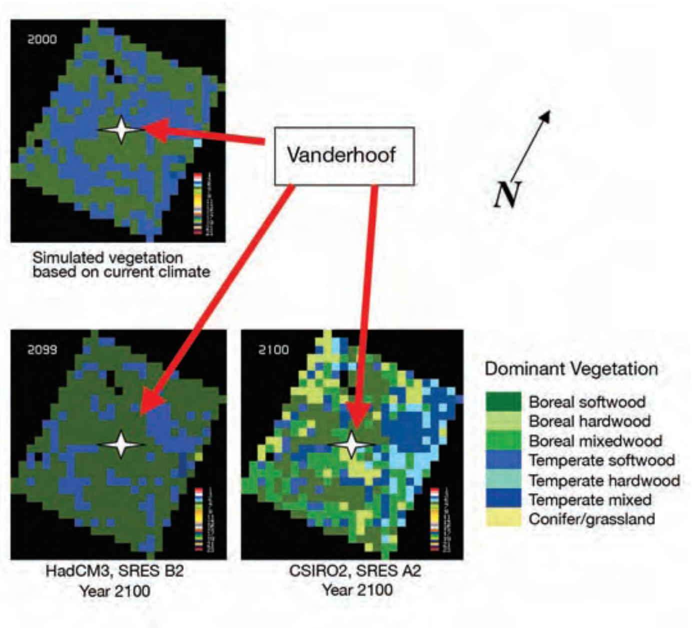


**FIGURE 12:** Simulated vegetation cover in the Vanderhoof study area, British Columbia (using IBIS, a dynamic global vegetation model), based on current climate and, at the turn of the next century, under two alternative climate scenarios (*Source*: D. Price, Natural Resources Canada). Study area is approximately 200 km by 200 km, with Vanderhoof at its centre. Each grid simulated by the IBIS model measures 10 km by 10 km.

and Range (MFR) established two interconnected initiatives to examine the potential future condition of forest ecosystems and to identify management responses. These initiatives recognize climate change as one important influence — along with global competition and new working relationships between governments and First Nations — on the future of forests, the forest sector and forest-based communities in BC. They reflect an effort to move from studying impacts to implementing adaptation.

In the fall of 2005, the MFR established a Climate Change Task Team to review potential impacts of climate change on provincial forest and range resources, identify knowledge gaps and develop recommendations on how the MFR could respond. Recommendations from the team were released in a report entitled *Preparing for Climate Change: Adapting to Impacts on British Columbia's Forest and Range Resources* (BC Ministry of Forests and Range, 2006). The Future Forest Ecosystems Initiative (FFEI), launched in December 2005, brought together representatives from academia, provincial and federal government agencies, First Nations, the forest industry, consultants and environmental organizations for a two-day symposium and workshop.

The MFR consulted widely on the reports of the Task Team and the FFEI. The recommendations from the reports and the consultations were amalgamated under the goal of adapting BC's forest management framework to changing climatic conditions. This will be achieved by increasing the understanding of ecological processes and the risks to forest ecosystems, and by communicating how to adapt the forest management framework to the changing environment. Strategies are being developed to meet these objectives. Although it will be a few years before operational adaptation actions are implemented, consultation, capacity building and vulnerability assessments are the first steps in the adaptation process.

## 4.3 SOUTHERN INTERIOR: OKANAGAN AND COLUMBIA BASIN REGIONS

The southern interior of British Columba includes the Okanagan region and the upper Columbia River basin. Both watersheds feed into the lower Columbia River system. The major climate adaptation challenge in both areas is the need to manage water resources for multiple, often competing uses. The Okanagan is experiencing rapid growth in population and irrigated agriculture, while the Columbia region is unique because of its importance to BC's hydroelectric power grid and the Columbia River Treaty with the United States. Both areas are also faced with issues concerning the management and conservation of fisheries resources. The discussion below reflects the fact that there is substantially more research available on the Okanagan.

### 4.3.1 Water Issues

The Okanagan is already experiencing stresses on its water systems associated with rapid population growth and land-use changes (Cohen et al., 2004, 2006). Recent droughts in 2001 and 2003 are examples of short-term extreme events that have affected water supply, water demand and perceptions of risk in the region. The drought of 2003 saw the emergence of local water conflicts (Moorhouse, 2003) and the implementation of both emergency and longer term conservation measures (Johnson, 2004). These droughts have raised awareness about climate sensitivities, and possibly about vulnerability to climate change. When coupled with anticipated population growth, concerns about fisheries and aquatic ecosystems, and long-term directions in regional development, the implications of future climatic change become an important addition to the concerns that need to be addressed by water planners and managers in this region.

The diversity of views in the region regarding the implications of climate change provided the foundation for a dialogue on how the region might adapt to climate change (Cohen et al., 2000). Research described potential impacts on hydrology and water management of the Columbia River system, including potential trade-offs between managing for hydroelectric production versus in-stream flows for fisheries (Payne et al., 2004). Within the Okanagan, case studies addressing hydrology and crop-water demand (Cohen and Kulkarni, 2001; Neilsen et al., 2001) were followed by collaborative work that included estimates of the region's water balance, considering both agricultural and residential water demand (Neilsen et al., 2004a,b). This also included adaptation experiences, a preliminary look at costs of adaptation options and a dialogue on potential implementation of adaptation options.

Climate change scenarios based on two emissions scenarios (A2 and B2) and three climate models were used to generate hydrological scenarios for various catchments in the Okanagan watershed for three time periods (2020s, 2050s and 2080s; Merritt et al., 2006). All results suggest an earlier snowmelt peak in spring, with reduced summer flows and increased winter flows, although the shape of this peak varies considerably (Figures 13 and 14). The hydrographs built from these scenarios proved to be an important tool for translating the implications of climate change into terms that are meaningful and tangible to local decision-makers.

Hydrological scenarios for the Okanagan watershed are similar to those for the Columbia River system as a whole. Maximum snowpack would occur up to 4 weeks earlier by the 2080s. Spring peak flow would be 15 to 40 days earlier by the 2050s, and 20 to 70 days earlier by the 2080s. Earlier and smaller snowpacks have a critical impact on the Columbia River system due to the snowpack's importance to the continuity of hydroelectric power generation (Columbia Mountain Institute for Applied Ecology, 2003). Annual supply from surface-water sources would vary from modest decreases to extreme reductions of around 65% by the 2080s (Merritt et al., 2006). At the same time, agricultural and residential water demand are projected to increase, thereby increasing the likelihood of water shortages. Crop-water demand in the 2080s would increase by up to 60% due to the longer and warmer growing season, although factors such as land-use change and carbon dioxide fertilization will affect this estimate (Neilsen et al., 2004a, 2006). A comparison between inflows to Lake Okanagan and projected crop-water demand shows that the overall ratio of demand to supply would increase from approximately 25 to 50% (Figure 15).

Anticipated population growth and a longer growing season could result in substantial increases in residential demand. A case study of Oliver, BC shows that demand could triple by the 2080s. Implementation of a portfolio of demand-side measures could slow down the projected increase in demand (Figure 16), buying time for the community to consider any requirements for increased water supply (Neale et al, 2006). Without specific measures to manage agricultural, residential and aquatic ecosystem maintenance demands, as part of a broader adaptation portfolio, total annual demand will exceed available annual inflows in the Okanagan watershed later this century (Langsdale et al., 2006).

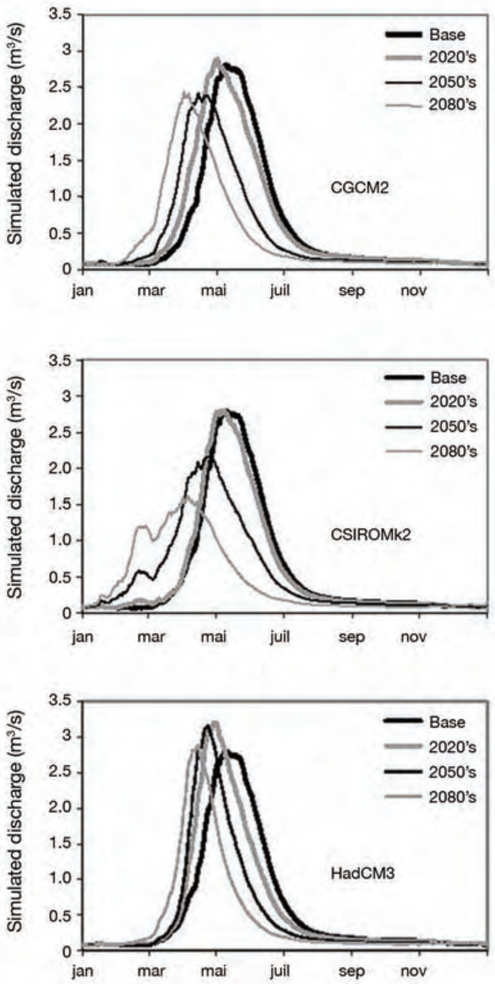


**FIGURE 13:** Hydrological scenarios for Whiteman Creek, British Columbia, using 3 models (CGCM2, CSIROMk2 and HadCM3) and the A2 emissions scenario (Merritt et al., 2006).

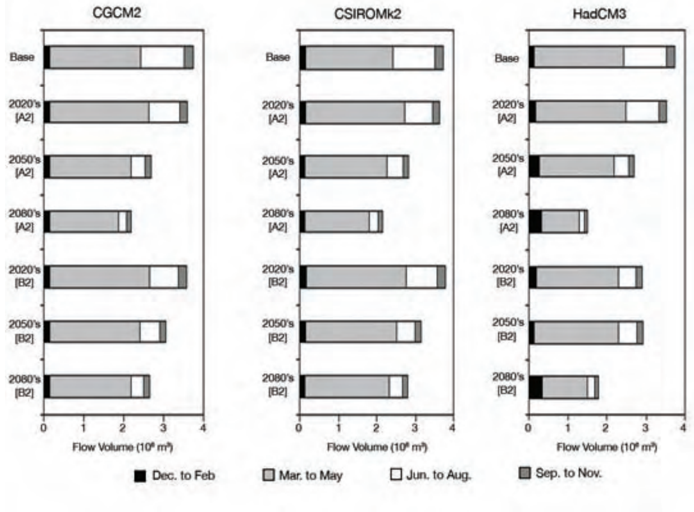
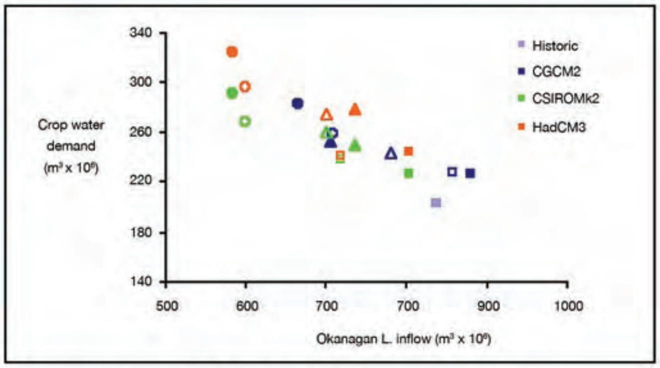


**FIGURE 14:** Projected hydrological responses in flow volume using three climate models and two emissions scenarios (A2 and B2) for Vaseux Creek, Okanagan watershed, British Columbia (Merritt et al., 2006).



*filled symbols are A2; open symbols are B2
squares = 2020s, triangles = 2050s, circles = 2080s

**FIGURE 15:** Projected changes in Okanagan Lake inflows and crop-water demand (Neilsen et al., 2004a).

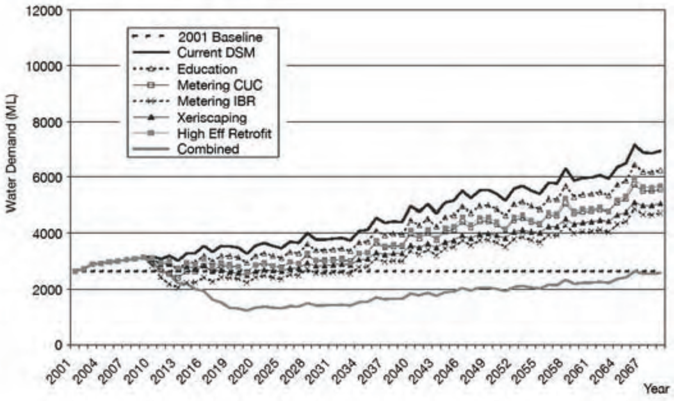


**FIGURE 16:** Projected changes in residential water demand, Oliver, British Columbia, due to population growth and climate change, and assumed application of demand-side adaptation measures (Neale et al, 2006).

### *Adaptation*

The Okanagan basin has had considerable experience adapting water systems to new challenges and opportunities. Examples include the regionalization of water delivery systems in Vernon, and the installation of meters in the Southeast Kelowna Irrigation District (SEKID) and the City of Kelowna. In SEKID's case, the trigger for action was dry conditions in 1987. Decisions were made through various means, sometimes aided by provincial incentives or influenced by environmental pressures or changing costs. So far, the SEKID and Kelowna cases appear to show that the measures were effective in reducing water demand, although it is too early to assess the outcome of regionalizing Vernon's water delivery (Shepherd et al., 2006).

In terms of adapting to future climate change, there is a wide range of measures available at varying costs (Hrasko and McNeill, 2006), recognizing that other factors in addition to cost will influence decision-making (Tansey and Langsdale, 2004). For example, dialogue participants in Oliver expressed interest in expanding usage of groundwater, and agreed with the need to be more efficient water users. However, they were concerned that improvements in efficiency of water use by agriculture might lead to a loss of water rights in favour of residential uses, and lead to rapid population growth. In Westbank, part of a planning unit known as the Trepanier Landscape Unit (TLU), an area experiencing rapid population growth, dialogue participants expressed interest in increasing water supply through pumping from Okanagan Lake and in improving efficiency through leak detection and other means.

A basin-wide workshop, held in Kelowna, was a more strategic discussion. Support was expressed for basin-wide integration of land and water planning, and a governance structure to reflect this. Concern was expressed regarding a perceived lack of public awareness of regional water resource problems, and the need for expanded public education. An important outcome of this participatory approach to climate impacts and adaptation research has been the explicit inclusion of climate change in the Trepanier Landscape Unit Water Management Plan (Summit Environmental, 2004).

## 4.3.2 Agriculture

Crop production in the Okanagan basin is entirely dependent on irrigation, and agriculture accounts for 75% of consumptive water use. Currently, the region supports mostly perennial crops (high-value tree fruits and wine grapes, with the balance in pasture and forage) and a small acreage of annual crops (silage corn, vegetables) planted in suitable microclimates. Economic production of high-value crops requires timely availability of water, both to assure quality and to protect investment in perennial plant material. Planned water deficits are used to enhance quality attributes in some crops, including wine grapes (Dry et al., 2001), while conserving water. Consequently, potential limitations and adaptation to the availability of irrigation water under current and future climates are important considerations for agriculture in BC.

Although changes in average climate will determine, in the long run, which crop production systems are viable in a region, extreme climate events present a greater challenge to adaptation (Intergovernmental Panel on Climate Change, 2001). The major risk facing Okanagan agriculture is the occurrence and frequency of drought, and the resultant lack of water that puts irrigation-dependent agriculture at risk.

Water demand models using climate scenarios from three GCMs and two emissions scenarios all project increased demand for water in the Okanagan basin, ranging from 12 to 20% in the 2020s, 24 to 38% in the 2050s to 40 to 61% in the 2080s (Neilsen et al., 2006), reflecting increases in peak demand and in growing season length (30 to 35% longer by 2100 for all crops). Increased evapotranspiration is the most important factor in the increase in crop-water demand. In a case study of one sub-basin (Trout Creek) with predominantly agricultural water demand, the frequency with which modelled crop-water demand exceeded a dam storage threshold increased over the century in response to all climate change scenarios (Neilsen et al., 2006). Coupled with increased drought frequency associated with climate change, it is apparent that the existing water infrastructure, typical of many upland storage reservoirs in the region, will be unable to meet demand in years of extreme climate.

### *Producer Vulnerability*

Two separate studies of the vulnerability of apple and grape producers to climate and other risks have been carried out in the Okanagan valley (Belliveau et al., 2006a, b), using methodology from Ford and Smit (2004). Producers were asked a structured series of questions to characterize good and bad years and the management strategies they used in response. All factors affecting production and returns were considered, with climate change and variability introduced only at the end of the survey.

The risks identified by apple and grape producers differed, despite co-location of the two industries. For grape growers, weather-related risks were critical (Figure 17) and confirmed by examination of long-term weather and crop production records (Table 12; Caprio and Quamme, 2002). Although apple growers also cited weather as a major concern in defining good and bad production years, market price was considered the most important determinant (Figure 17). A combination of low market prices and bad weather resulting in lower quality fruit was identified as the worst-case scenario. As with the grape growers, winter kill and cold damage, as well as high summer temperatures and damage from hail storms, are the main climate-related concerns.

Both grape and apple growers have adapted in order to minimize risk (Table 13). For both products, fruit quality is the major determinant of price; thus, considerable effort is aimed at achieving the highest quality crop. A number of practices can be used to offset weather effects, including frost protection using irrigation or wind machines, heat stress protection using irrigation for evaporative cooling, and increased disease and pest management in cool wet years. There are also non-horticultural responses to weather, such as changing the type of wine

**TABLE 12:** Major climatic factors defining suitability for woody perennial crops in British Columbia (after Caprio and Quamme, 2002).

| Phenological stage | Plant factor | Climate effect | Apple | Cherry | Apricot/peach | Grape |
|---|---|---|---|---|---|---|
| **Current year** | | | | | | |
| Dormancy | Winter hardiness | Detrimental | < –7°C to < –29°C from Nov. to Feb. | < –13°C to < –24°C from Nov. to Feb. | < –13°C to < –24°C from Nov. to Feb. | < –6°C to < –23°C from Nov. to Feb. |
| | De-acclimation | Detrimental | > 5°C in Jan. | | | > 9°C from Nov. to Dec. |
| | Root protection | Beneficial | | Snowfall | Snowfall | Snowfall in Jan. |
| Bloom | Spring frost injury | Detrimental | < 5°C | < –2°C | < –2°C | |
| Pollination/pollen tube growth | Outside optimum temperature range | Detrimental | > 28°C day; < 10°C night | | | |
| | | Beneficial | > 21°C day; > 11°C night | > 16°C | > 16°C | |
| Fruit-cell division and expansion | Outside optimum temperature range | Detrimental | > 33°C Aug. | > 33°C to > 37°C at harvest | > 31°C at harvest | > 32°C Jul. to early Aug. (veraison[1]) |
| | Cherry cracking/ disease/reduced photosynthesis | Detrimental | | Rainfall just before and during harvest | | Rainfall at any time (disease) |
| | | Beneficial | > 17°C at harvest | | | > 26°C entire season |
| **Previous season** | | | | | | |
| Flower-bud initiation | Outside optimum temperature range | Detrimental | > 30°C Jun. | | | > 32°C |
| | | Beneficial | | | | > 26°C (other than mid-Jul.) |
| Flower-bud development | Outside optimum temperature range | Detrimental | > 26°C Aug. | | > 27°C Aug. | |
| | Reduced photosynthesis/disease | Detrimental | | Precipitation | Precipitation | |
| | | Beneficial | | >19°C from Sep. to Oct. | >26°C from Sep.to Oct. | > 26°C (other than mid-Jul.) |

[1] physiological stage when grapes start to colour

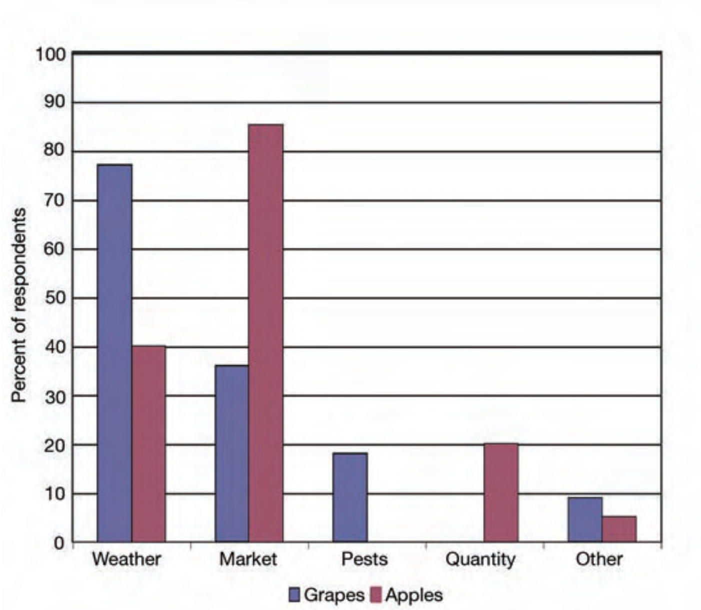


**FIGURE 17:** Risks that characterize bad economic years, as identified by grape and apple producers, Okanagan valley, British Columbia (Belliveau et al., 2006a, b).

produced or shipping fruit for processing, rather than fresh to market. Crop insurance is a major risk management strategy employed by 85% of apple growers and 72% of grape growers to offset losses due to weather.

Risk management strategies to handle one problem may inadvertently increase risk in another. For example, two government sponsored strategies — the grape pullout program in 1988 and the apple replant program from 1992 onwards — have inadvertently increased vulnerability to climate risk. In the case of grapes, cold-hardy hybrid varieties have been replaced by more tender varieties and, in the case of apples, dwarfing rootstocks have increased susceptibility to winter root damage and apple sunburn. Support programs, such as the Canadian Agriculture Income Stabilization program, may also undermine measures taken by producers to reduce climate risks. For example, diversification of varieties by apple growers may mean that failure in one crop is masked by success in another, thus disqualifying the farm for income assistance. Similarly, diversification of location by grape growers may prevent loss of crop in one location from being compensated for if other locations are unaffected, unless each location is covered by a separate agreement.

Average temperature increases of 1.5 to 4.0°C, projected by the 2050s for this region, may create opportunities for grape growers to grow later maturing varieties or those requiring more heat units to achieve higher quality. Apple producers may also be able to grow longer season varieties. However, risks from spring and fall frost will likely remain the same or possibly increase if advances in bloom date are not accompanied by equivalent decreases in frost risk. Excessively high temperatures in the summer, however, might decrease suitability for apple growing. Irrigated perennial crops, such as tree fruits and grapes, require large investment ($15 000–20 000/ha) in plant material and infrastructure. Varying lengths of time, depending on crop type (5–10 years), are needed to show a return on investment, and plantings may be expected to last 15 to 20 years. Although horticultural techniques exist (e.g. grafting) to change specific varieties mid-stream, such production systems are inherently less flexible than annual crop farming and therefore more vulnerable to climate change.

**TABLE 13:** Farm-level adaptations by Okanagan valley grape and apple producers in bad years (Belliveau et al., 2006a, b).

| Stimulus | Adaptations | |
|---|---|---|
| | Grape producers | Apple producers |
| **Weather** | | |
| Cold, wet season | - Remove crop and shoots, additional spraying for mildew<br>- Make sparkling wines<br>- Lower price of wine | |
| Frost | - Irrigate<br>- Wind machines<br>- Crop insurance<br>- Choose an early-maturing variety | - Irrigate<br>- Wind machines<br>- Crop insurance |
| Extreme heat | Irrigate | - Irrigate<br>- Diversify household income (spouse works off farm) |
| Hail | | - Crop insurance<br>- Send salvaged fruit to packing house |
| Fire/smoke damage | Crop insurance | |
| **Market** | | |
| Low prices | | - Tighten budget/reduce spending<br>- Change crop varieties<br>- Produce high-quality fruit<br>- Income stabilization<br>- Diversify household income |
| Low tourism | - Be more aggressive in other market channels<br>Increase local sales | |

### 4.3.3 Aquatic Ecosystems and Fisheries

During the past century, the original mosaic of terrestrial and aquatic ecosystems within the Okanagan River basin has become increasingly dominated by human activities. One-third of all plant and animal species listed as being at imminent risk of extinction in British Columbia are found in Okanagan basin ecosystems (Bezener et al., 2004). Eighty-five per cent of valley bottom wetland and riparian habitats have been lost to human activity and disruption (BC Ministry of Environment, 1998). Over the past 30 years, recreational and First Nation salmon fisheries, afforded constitutional protection, have been virtually eliminated throughout the basin (Hyatt and Rankin, 1999; Andrusak et al., 2002). Migratory species, such as sockeye (*Oncorhynchus nerka*) and steelhead (*Oncorhynchus mykiss*) salmon, are subject to both domestic and international conservation and management objectives and agreements. Long-term maintenance and restoration of aquatic ecosystems and native fish populations in the Okanagan valley represent a significant challenge with complex regional, national and international dimensions (e.g. Shepard and Argue, 2005).

Attempts to restore salmon populations in the Okanagan-Columbia basin (e.g. Wright, 2004) are part of an extensive effort to manage regional aquatic ecosystems for multiple objectives that include hydroelectric power generation, irrigation, navigation, flood control, recreation, municipal and industrial water supply, and fish and wildlife habitat (Lee, 1993). Climate change poses a significant challenge to these efforts in general, and to the conservation and restoration of depressed salmon populations in particular, because climate change affects the quantity and quality of seasonal water supplies that control habitat features (temperature, oxygen levels, flow and nutrient loading) critical to salmon. Higher water temperatures, plus changes in volume and timing of stream flow, will create conditions that are increasingly inhospitable to salmon in the Okanagan and Columbia basins (Hyatt et al., 2003; Casola et al., 2005). Such climate change impacts will exacerbate existing conflicts (Whitfield and Canon, 2000; Moorhouse, 2003) and create new ones over allocation of limited water supplies to maintain lake levels and in-stream flows for fish, versus water for other consumptive uses at regional and international scales (Pulwarty and Redmond, 1997; Payne et al., 2004).

There is a long history of dialogue and actions to satisfy competing water management objectives in the Okanagan basin (Hourston et al., 1954; Anonymous, 1974; Cohen and Kulkarni, 2001). Thus, many details of the current water management framework are specified as prescriptive elements of national (Canada–British Columbia Okanagan Basin Agreement, or OBA) or international (Canada–United States) agreements. The OBA specifically recognizes that water management decisions influence aquatic ecosystems and fish production, so provisions of the agreement focus on control of lake- and river-discharge levels that are adjusted seasonally to protect the productive capacity of salmon populations throughout the system (Anonymous, 1974). Poor compliance with lake elevation and discharge provisions of the OBA (Bull, 1999) has been attributed to the complexity of balancing fisheries, flood control and water allocation objectives (Alexander et al., 2005).

#### *Adaptation*

Climate change further complicates the difficult task of balancing competing objectives of managing water supplies for both maintenance of natural ecosystems and the engineered systems that increasingly dominate the Okanagan and Columbia basins. Although decades of experience in American portions of the Columbia River basin suggest that future increases in conflict over water management objectives may be inevitable (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, 1996), they also underscore the value of searching for viable adaptive responses to eliminate or minimize conflict whenever possible. Potential avenues include 1) developing and maintaining an informed dialogue among government agencies, industry and local communities (e.g. Tansey and Langsdale, 2004) to address competing water management objectives; 2) establishing increased levels of co-operation and integration among all groups involved in specifying and maintaining water management frameworks; and 3) developing leading-edge science and technology to provide resource managers with new tools to satisfy key information needs for complex water management decisions (Hyatt and Alexander, 2005).

## 4.4 METROPOLITAN REGIONS: VANCOUVER AND VICTORIA

The Greater Vancouver Regional District (GVRD) and the Victoria Capital Regional District (CRD) form the economic and political hub of British Columbia. Although adapting to climate change is typically not at the forefront of city managers' and leaders' minds, it is an emerging issue on the management and planning agendas of some departments and decision-makers. This section provides a brief summary of two key challenges that face BC's most populous districts: water supply and stormwater management.

### 4.4.1 Water Supply Management

Both the CRD and GVRD face the familiar challenge of managing water supplies in the face of rising population, aging infrastructure and changing climate. The Sooke Reservoir on southern Vancouver Island is the main water supply to the CRD. The region's climate is characterized by mild wet winters and warm dry summers. The area's water balance has a winter surplus of 1226 mm during times of reservoir filling and a summer deficit of 138 mm when reservoir drawdown occurs. Thus, there is a natural mismatch between water supply and water use in the region (Figure 18), as is common for many watersheds in coastal BC. Also, there is considerable inter-annual and inter-decadal variability in seasonal precipitation, with periods of water surplus and extreme water shortages being common since the early 1980s (Figure 19). The PDO significantly influences this variability and the reservoir's water budget (Figure 19).

In response to severe droughts and expected continued population growth, the CRD raised the level of the Sooke Reservoir by 6 m in 2002, increasing storage capacity by 78%

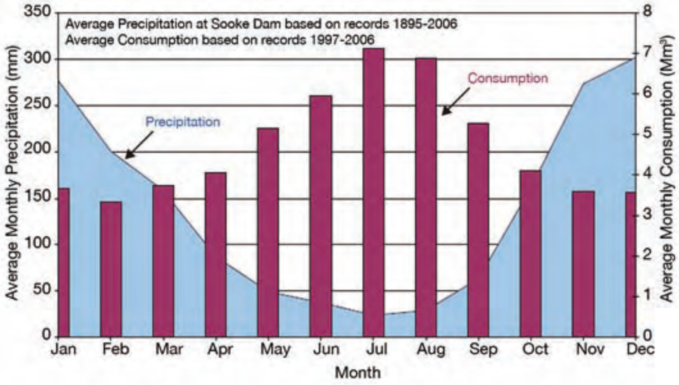


**FIGURE 18:** Average precipitation inputs and consumption withdrawals from the Sooke Reservoir, southern Vancouver Island, British Columbia (*from* Capital Regional District Water Services, 2007).

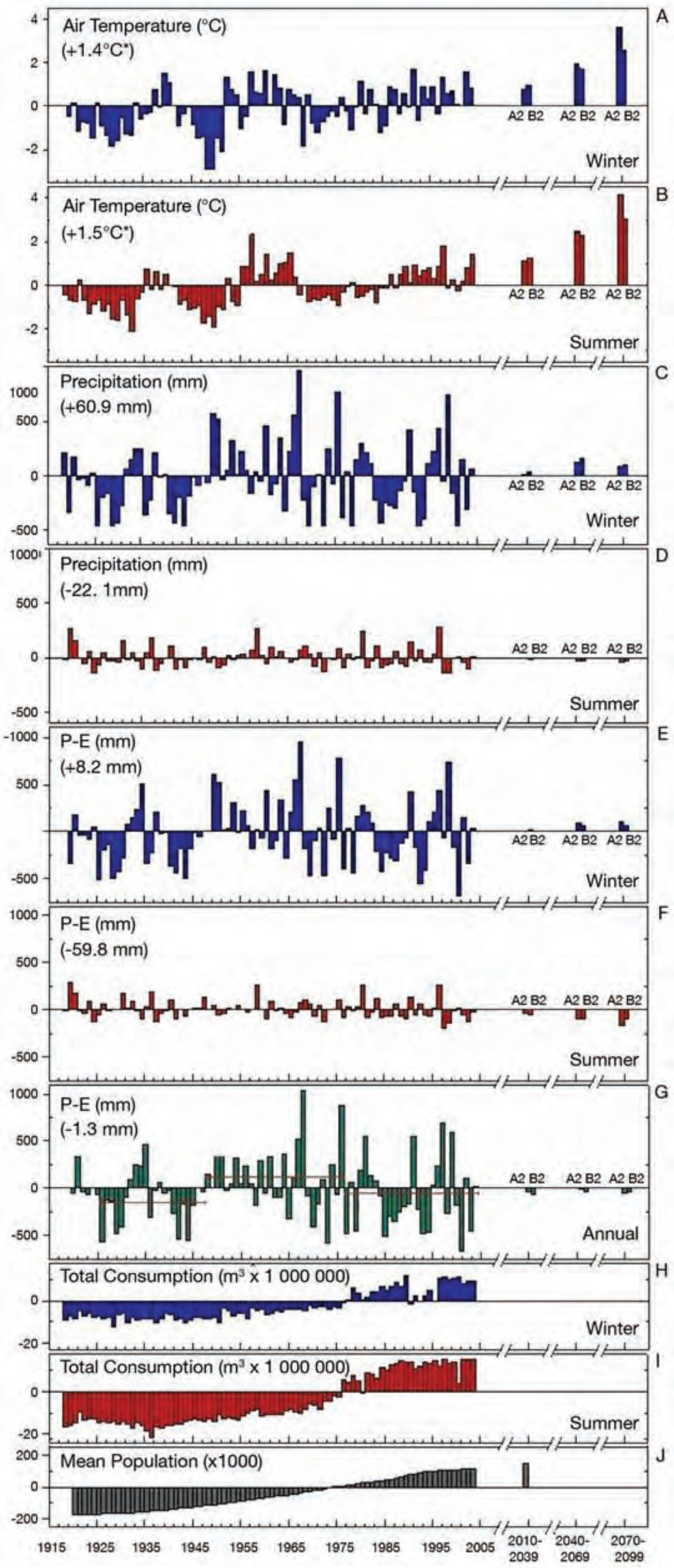


**FIGURE 19:** Winter (October–March) and summer (April–September) departures of Sooke Reservoir water supply variables relative to 1961–1990 mean values (linear trends over the 87-year period provided in brackets; * signifies trends significant at the 0.05 level). Temperature, precipitation and consumption data provided by the Capital Regional District. Note that 1966–1994 temperature and 1971–1977 consumption values are estimates. Evaporation was estimated using day length and air temperature (per Hamon, 1963). Future temperature, precipitation and precipitation-evaporation values for 30-year periods centred on the 2020s, 2050s, and 2080s are also shown. Projections are based on ensemble averages for the A2 and B2 emissions scenarios using the seven global climate models recommended by the Intergovernmental Panel on Climate Change (2001).

(Capital Regional District Water Services, 2004). Based on historical climate conditions and a maximum growth rate of approximately 1%, the expanded reservoir capacity will only meet projected demands until 2023 (Capital Regional District Water Services, 2004). The CRD has implemented several conservation and demand-management initiatives, including residential water metering, multi-stage lawn watering restrictions and rebates for high-efficiency equipment (toilets, washing machines), to offset the demand increase.

The GVRD's water supply comes from the Capilano, Seymour and Coquitlam watersheds, located in the Coast Mountains along the northern fringe of the city. These watersheds have a much wetter and colder climate than Sooke, with significant runoff occurring in spring and fall, and snow accumulation during winter. There is large storage capacity during the summer in six mountain reservoirs. Current constraints on GVRD water supply are associated with the ability of system infrastructure, specifically pipelines, water intakes and water treatment facilities, to meet rising demand from an increasing population.

In future, climate change will result in a decreased snow pack as a greater proportion of annual precipitation falls as rain. In conjunction with longer drier summers, infrastructure will be further stressed, especially during periods of peak seasonal demand. Climate change will likely advance the time when upgrades and capital investments are required for additional storage capacity. Demand management and water conservation programs are important first steps and should help delay the timing of capacity upgrades. The GVRD's Drinking Water Management Plan (DWMP) does include provisions for ongoing assessment and monitoring, including biennial progress reports that consider the potential impacts of climate change on supply and the implications for capacity upgrade planning (Greater Vancouver Regional District, 2005a, b).

Both of BC's principal metropolitan areas have already taken steps to anticipate some impact of climate change on water supplies. These impacts will increase the pressure of rising populations and demand, and effectively bring forward the date when current supplies will be insufficient. Ongoing conservation and demand management represent key adaptation strategies, even if they are not explicitly implemented as such. Longer term adaptation actions are likely to involve further infrastructure upgrades and increased storage capacity.

### 4.4.2 Stormwater Management

Since 2000, the Greater Vancouver Regional District (GVRD) has been examining the potential risks from climate change on sewer and drainage infrastructure. Trend analysis of more than 40 years of rainfall data indicated an increase in the frequency of extreme rainfall events, such that the recurrence interval of 25 years for an extreme event (4% probability in any given year) had decreased to about 10 years (10% probability; Jakob et al., 2003). Research concluded that observed increases in the frequency of intense rainfall could be correlated with the 1976 phase shift of the PDO. As the present methodology used to generate the rainfall intensity-duration curves for sewer design and stormwater management does not explicitly take into account climate oscillations, it remains possible that rainfall intensity-duration curves could be over- or underestimated, depending on when the majority of rainfall data were collected.

Jakob et al. (2003) also noted that statistically measurable increases in the non-extreme rainfall intensity and volume were evident, and they interpreted these to relate to larger scale climate change. Such increases, although not impacting sewer design, are anticipated to negatively impact the health of urban streams and their populations of salmon and trout. These impacts are similar to those from urbanization and the associated construction of hard surfaces (roofs, roadways, etc). The Water Balance Model for Canada, and the GVRD's design guidelines for stormwater source controls (Lanarc Consultants, 2005) were developed as tools for GVRD municipalities to address the effects of urbanization and climate change on urban streams (Hicks and von Euw, 2004). These represent a first step in the explicit recognition and inclusion of observed and future climate change impacts on urban infrastructure in BC. A pracitioner's perspective on this issue and the role of risk management approaches are presented in Box 3.

**BOX 3**

### Climate change and risk management: a practitioner's perspective

*(Robert Hicks, P.Eng., Member, British Columbia Water and Waste Association, Water Sustainability Committee)*

Fundamental to local governments is the provision of basic services to their communities. Core services include potable water supplies, streets and roads, and land-use planning, while more comprehensive services include libraries, public housing, and parks and recreation. Municipalities and regional districts form the basis for local governments in British Columbia. 'Improvement districts' effectively form another level of local governance that provides limited function-specific services, such as rural water distribution, flood protection and dyking.

Significant obstacles to climate change adaptation arise from the competition for funding between short-term priorities and long-term risk management. For any community experiencing pressures on a limited tax base or facing significant core infrastructure costs, it is questionable whether there would be the financial means or will to address climate change impacts as a priority. The weighing of priorities is further complicated by difficulties in quantifying the long-term benefits of climate change adaptation programs and/or by the lack of understanding of climate change issues.

**Risk Management**

Although local governments face challenges in addressing climate change adaptation as a stand-alone issue, they are experienced risk managers, particularly with respect to the provision of their utility services and maintaining their capital assets (roads, bridges, buildings, pipelines). The life cycles of roads, sewer and water systems, and community buildings range from 20 years to a century or more. Such assets are managed with respect to risk of service interruption, level of performance, control of operating costs, and planning and budgeting for replacement and renewal. It is through this context that local governments are well situated to address impacts from climate change as an additional risk related to their provision of municipal services.

Addressing climate change risks related to land use and zoning is more challenging for local governments. It is possible that some proactive adaptation responses might exceed municipal mandates and be difficult to implement. Without compelling justification, local governments are unlikely to implement programs and zoning changes that would adversely affect the value or utility of private lands.

Climate change impact awareness and skills are needed for climate change adaptation to be effectively integrated into day-to-day local government planning and risk management processes. The use of return periods — commonly used to describe technical design thresholds and performance targets for stormwater, drainage, sewers and water supply systems — create a false sense of understanding, as they are based upon past events. Return periods are common in regulations and in 'standard engineering practice'. However, using return periods without considering their response to climate variability and climate change is like 'driving a car through the rear-view mirror, it only works if the path is linear'. Consequently, the use of return periods could result in poor long-term decision-making and prevent proactive adaptation if not put into the context of climate change.

# 5 CONCLUSIONS

## 5.1 KEY MESSAGES AND THEMES

**Climate change impacts and the costs of extreme events are increasingly evident but responses and adaptation measures remain reactive.**

Although well-known ocean-atmospheric cycles, such as ENSO and PDO, are the drivers of short- and long-term climate cycles and weather extremes in British Columbia, there is strong evidence linking global climate change to increasing climate variability and extreme events (Sections 2.1 and 2.3). During the past century, the province warmed significantly across all seasons, and projections of future climate change suggest continued warming for all seasons, wetter conditions for much of BC in winter and spring, but drier conditions during summer in the south and on the coast (Section 2.2).

Changes in the amount and type of precipitation, mainly more rain and less snow, are already evident in BC. Persistent droughts are common during summer months. Prehistoric climate records show that severe droughts occurred more frequently in previous centuries than during the past few decades (Section 2.1), suggesting that BC can expect more severe droughts in the future, irrespective of climate change.

Most of BC's alpine glaciers are retreating rapidly and many may disappear in the next 100 years (*see* Box 1). Coupled with reduced snowpack and warmer spring temperatures, this will result in earlier spring freshets, warmer river temperatures, declining summer river flows and increasing peak flows for many of BC's watersheds (Section 2.4). Impacts on current and future water supplies, hydroelectric power generation, fisheries and river ecosystem integrity are significant concerns for BC. These changes will pose numerous challenges for water managers and other users, and increase the likelihood of inter-sectoral and transborder water conflicts (Section 3.1).

Geological effects will offset or exacerbate global trends in sea-level rise on the BC coast. Superimposed on sea-level rise is increasing extreme water levels driven by climatic variability events. Accelerated coastal erosion and flooding are expected to pose ongoing and increasing hazards for BC's coastal communities and infrastructure (Sections 2.5 and 4.1).

The frequency of, and costs associated with, most types of extreme weather events and related natural hazards (e.g. coastal storms and surges, forest fires, droughts, landslides) are increasing (Section 2.3). Most climate-related adaptations in BC are reactive responses to such 'surprises' as the unprecedented mountain pine beetle outbreak or the extreme forest fires of 2003. Examples of adaptation planned specifically for climate change are scarce. In some respects, this relates to a limited perception of climate change as a risk to the livelihoods, activities and economies that support British Columbia; in other cases, it is a matter of other priorities competing for limited capacity. As climate change is only one of many stressors that affect the province's industries, communities and ecosystems, a 'cumulative impact' perspective may be most appropriate for adaptation planning. There are several examples of recent studies and risk assessments involving researchers, community groups and decision-makers in BC (*see* Section 4) that represent an important first step towards a more comprehensive approach to planned adaptation. Awareness of the current and potential impacts of climate change and understanding of the need to address adaptation as well as mitigation is growing in communities around the province.

**Management of increasingly frequent and severe water shortages will entail complex trade-offs and require improved consideration of climate change.**

Retreating glaciers, declining snowpack, increasing drought, and shifts in timing and amount of precipitation will increasingly limit water supply during peak demand periods for hydroelectric power generation, agriculture and drinking water, although this may be partially offset in some regions by increased precipitation. Approximately 78% of British Columbia's population depends on surface-water supplies for drinking, while 89% of the province's electricity comes from water (Sections 3.1 and 3.7). Declining water supplies raise numerous management challenges, particularly in such areas of rapid growth as the Greater Vancouver Regional District (GVRD), the Capital Region District (CRD; i.e. Victoria and surrounding municipalities), the Okanagan region and even certain small communities such as Tofino. Increasing conflict between supply and demand will necessitate trade-offs between alternative uses and values (e.g. maintaining stream levels for fisheries habitat versus irrigation needs for agriculture).

Since the 1980s, BC's major urban centres have experienced several extreme summer droughts and water resource limitations. Drinking water supplies may become stressed in the CRD and the GVRD. Increasing future supplies will require significant infrastructure upgrades and demand management strategies (Section 4.4.1). This is also a concern for smaller rapidly developing areas (e.g. Tofino-Ucluelet). The CRD recently completed a substantial upgrade to increase storage capacity of its main water source, the Sooke Reservoir. To avoid the need for major new infrastructure investment, the CRD aims to implement aggressive demand management measures to meet demand over the next 50 years. The GVRD is also aware of potential challenges presented by increasing demand and climate change impacts, and is planning for increased storage capacity and enhanced demand management.

British Columbia's hydroelectric power generation capacity is currently vulnerable to declining water supply and changing river flow patterns, most notably in the Columbia River basin, where more than half of the province's hydroelectricity originates. By 2025, electricity demand in BC is expected to be 30 to 60% higher than in 2005. Targets set by the recently released BC Energy Plan include aims to meet 50% of incremental growth through conservation and efficiency measures, and to generate at least half of all new power from renewable sources, such as wind, geothermal, biomass and hydro. The connection between climate change and water will be an increasingly important consideration in planning to meet many of the key energy production and mitigation strategies outlined in the plan.

Current institutional and planning structures, for the most part, do not consider existing climate variability or future projections of climate change in the management of water resources. Climate change considerations could be effectively integrated with land-use, community planning or resource management processes.

**British Columbia's critical infrastructure faces immediate challenges and long-term threats from climate variability and change.**

Extreme weather and associated natural hazards currently present challenges to British Columbia's critical infrastructure, and these impacts are projected to increase as a result of continued climate change. In many places, critical infrastructure, including pipelines, power and telecommunication transmission lines, and transportation networks, are geographically confined to narrow valleys and coastal stretches, and therefore vulnerable to disruption from natural hazards, such as landslides, coastal storms and surges, flooding and forest fires. Research on the impacts of climate change on BC's critical infrastructure systems remains limited, while insurance and costs for emergency response and recovery are rising (Section 3.8).

Central and northern communities, such as Prince George, report increases in road maintenance and flood management costs directly or indirectly related to changing climate conditions. Climate change impacts are now being considered in the GVRD's Integrated Stormwater Management Plans (Section 4.4.2).

Life-cycle cost analysis, return period statistics for extreme events and engineering standards all influence management decisions on how or when to maintain or replace infrastructure. Updating these analyses, statistics and design standards so that they consider climate change impacts and trends will enable managers to better plan for future changes. Institutional constraints remain, however, as many standards and policies that guide infrastructure decisions rely only on past climate statistics.

**British Columbia's forests, forest industry and forestry-dependent communities are vulnerable to increasing climate-related risks.**

Forestry remains a cornerstone of the BC economy. British Columbia's forest resources are vulnerable to a host of impacts related to changing climate conditions, including fires, pests, disease and ecosystem shifts. Conditions conducive to forest fires are expected to increase (Sections 2.3 and 3.3) and will lead to an increase in associated health risks (Section 3.9) and post-wildfire flood and landslide hazards (Section 3.3).

The current mountain pine beetle (MPB) outbreak affects almost 10% of BC's land base. At 9.2 million ha in 2006, this outbreak is unprecedented in its extent and longevity (Section 4.2). Past forest fire suppression and management, drought conditions in the 1990s and warmer winter temperatures have provided favourable conditions for the current outbreak. The infestation is advancing into northeastern BC, and projections of future climatic suitability for MPB suggest that continued eastward expansion into the boreal forest is highly likely.

Communities are responding quickly to the MPB infestation. Vanderhoof, in north-central BC, is exploring adaptation options to manage future opportunities as they transition from a pre- to a post-beetle economy (Section 4.2.1). Prince George is surrounded by MPB-devastated forests and, like other communities in the interior, is experiencing increased economic activity from expanded salvage logging operations. This short-term economic gain from beetle-killed trees will have long-term ecological, hydrological and economic implications. City planners in Prince George are concerned about the increased flooding potential of the Nechako and Fraser rivers as trees are removed from surrounding watersheds. Many forest-based communities will face substantial economic challenges once the current round of logging has cleared beetle-killed trees, as it will take almost a generation for resource stocks to replenish.

The long growth period before trees are ready for harvest means that much of the resource that will support the forest industry and communities for the next few decades is already in the ground. Forest management options are limited if site productivity is affected and existing species turn out to be poorly suited to changing conditions. Similarly, the industry has invested in large equipment and processing facilities that are difficult and expensive to adapt. These long investment periods increase the risk and uncertainty for both the industry and dependent communities to the impacts of climate change and to challenges such as international market competition.

The BC Ministry of Forests and Range has developed a 'Future Forests Ecosystem Initiative' that incorporates climate change adaptation into forest management (Section 4.2.2). This initiative is an early step toward long-term forest planning that includes climate change in conjunction with other pressures, including international competition, forest health, increases in forest fire regimes, and changing social and economic conditions.

**Existing stresses on British Columbia's fisheries will be exacerbated by climate change.**

The social, cultural and ecological importance of fisheries in British Columbia far exceeds their relatively small economic contribution to the provincial GDP. Fisheries are especially important to coastal communities and First Nations, they attract thousands for sport-fishing tourism, and they are key indicators of water quality and ecosystem health. Most capture fisheries are either stable or declining, whereas aquaculture continues to grow steadily (Section 3.2).

Salmon far outweigh other species in terms of social, economic and cultural importance in BC. Coastal salmon fisheries are already under stress from a combination of factors, including habitat loss in spawning watersheds and overfishing. Climate change will cause further stress as water temperatures rise and through indirect effects on other sectors, such as the influence of MPB-related tree mortality on hydrology. Northward migrations of exotic fish species from warmer southern waters already threaten young salmon during warm El Niño events. Continued ocean warming as a result of climate change will pose a longer term and more severe threat to salmon and other coastal fisheries.

Inland fish populations, including migratory salmon, are sensitive to increasing water temperatures and to changes in river and lake levels. Climate change impacts on water resources are a major concern for inland fisheries (Section 4.3.3). Constitutional guarantees of access to fisheries for First Nations' use give fisheries some priority. Management conflicts between in-stream water needs for fish, hydroelectric power generation, irrigation, and domestic consumption are likely to increase with continuing climate change and future treaty negotiations.

Adaptation to climate change in the fisheries sector involves primarily management responses that protect or enhance stocks. Potential adaptation measures include reducing harvest rates, reinforcing habitat protection and restoration, increasing hatchery production of salmon, licensing and regulating river systems, promoting accelerated development of aquaculture and/or diversifying fisheries to take advantage of short- and long-lived species and exotics as traditional single-species fisheries decline.

**British Columbia's agricultural sector will see increasing threats and some opportunities from climate change.**

Similar to fisheries, agriculture makes only a modest contribution to British Columbia's economy, but indirect benefits and employment are substantial. Agriculture, particularly the wine industry and orchards, is a lucrative component of tourism in areas such as the Okanagan valley. Farming and ranching are also important in many rural regions. Suitable lands for farming in BC are limited to approximately 4.5% of the land base (approx. 4.7 million ha), and much of this is protected by BC's agricultural land reserve (ALR; Section 3.4). The greatest threat to agriculture from climate change in BC is the impact on water resources. This results not only from increasing water scarcity and extended drought, but also from heightened competition with other uses. Increases in extreme weather, associated natural hazards, and outbreaks of pests and disease are also of concern.

Climate change also presents potential opportunities for agriculture in BC as a result of longer growing seasons and milder winters, which could increase the range and/or number of economically viable crops that can be grown (Section 3.4). Constraints on this potential opportunity include limited soil suitability, water supply, irrigation infrastructure and transportation distance to markets. Isolated valleys of quality agricultural land (e.g. Bella Coola valley) may be the greatest beneficiaries. Introduction of new and potentially more lucrative crops into existing agricultural regions has also been considered, although these perceived opportunities will face development and water availability challenges similar to those that currently face existing crops, with added risks as a result of climate change.

Farmers' experience in dealing with climate variability and extreme weather events, disease and crop failures, and market fluctuations results in considerable capacity to adapt to climate change. Strategies include both long- and short-term approaches, such as diversification of crops where possible and alternate processing techniques. Support programs designed to help farmers manage market-related risks and occasional crop failures are a good hedge against crop losses caused by climate variability and extreme events, but may also serve as disincentives for adaptation to longer term climate change.

**Integrating climate change adaptation into decision-making is an opportunity to reduce long-term costs and impacts on British Columbia's communities and economy.**

Enhancing adaptive capacity and implementing adaptation measures to climate change does not require managing or planning resources and infrastructure in a whole new way. Rather, opportunities to improve the effectiveness and reduce the costs of adapting to climate change impacts exist through integration of climate change information into existing planning, management and decision-making processes. Existing datasets, simulation models and scenarios, and seasonal climate forecasts that incorporate climate change and related impacts can inform ongoing management and planning decisions (Sections 2.1 and 2.2).

Currently, climate change is being considered indirectly in a variety of settings to inform or guide decision-making. Experience in the Okanagan illustrates the importance of translating climate change scenarios and impacts into terms and language relevant for local planning and management (Section 4.3.1). In Vanderhoof, a community pilot project is underway to develop and test methods for assessing the vulnerabilities and adaptive capacity to forest changes using simulation models, surveys and interviews within the community (Section 4.2.1). Similarly, researchers are working with councillors, planners and engineers in the Corporation of Delta to understand impacts and vulnerabilities to storm surges and sea-level rise (Section 4.1.2). This type of community-based research is seen as an important first step to integrating climate change into local and regional planning.

British Columbia's most populated regional districts are pursuing sustainable development and climate change mitigation initiatives, some of which include adaptive benefits. Among these are water and energy conservation measures that include design features, materials, equipment and/or processes that use or recycle energy and water within the building plant. Such practices reduce greenhouse gas emissions from building operations (mitigation) and place less demand on city infrastructure and resources (adaptation).

**Vulnerabilities and adaptive capacity vary widely across regions, scales and economic sectors in British Columbia.**

There are significant differences between rural and urban British Columbia with respect to climate change vulnerabilities and adaptive capacity. These are largely a function of economic dependence. Reliance on natural resources is most pronounced in remote rural and coastal communities, whereas urban areas have more diversified economies.

Vancouver and, to a lesser extent, Victoria have increasingly diversified economies based on information, technology, tourism and related service sector activity, in conjunction with transportation, finance, port and government functions. Their dependence on BC's resource economy is indirect and, while still significant, is largely surpassed by post-industrial economic drivers. In contrast, rural BC remains intimately dependent on natural resources, particularly forestry and fisheries. The sustainability of rural communities will depend, to a large degree, on how they are able to cope with changes to their resource base(s). This involves planning to manage both risks and opportunities. There is some evidence of communities adapting to the new global economy in ways that bypass dependence on metropolitan centres, suggesting increasing capacity to deal with change in general, and increased ability to manage resource dependence in particular (Section 1.4).

In remote coastal communities, resilience and adaptive capacity emerge from a variety of sources, including 1) the strength of local and regional institutions; 2) patterns of local social and economic development; 3) the nature and condition of critical infrastructure; and 4) level of experience with extreme weather and exposure to other forms of environmental and/or socioeconomic change. In addition, income diversification, self-reliance, volunteerism and strong social networks and cohesion are all important factors that contribute to a remote community's capacity to adapt to broader issues such as climate change (Section 4.1.1).

Social, cultural and economic factors may limit capacity to undertake climate change adaptation at the community level. Many coastal and rural BC communities are currently experiencing significant social and economic hardship due to multiple stressors. Resilience based on social capital and strong social cohesion enable some communities to cope with these stresses, even where other attributes of adaptive capacity are limited (e.g. access to physical and financial capital, technology, expertise and other resources). The key challenge for enhancing adaptive capacity in such locations is to build on initiatives that currently address economic and environmental changes, by including consideration of the impacts of climate change.

## 5.2 BUILDING ADAPTIVE CAPACITY

Steps to enhance adaptive capacity must be locally relevant, oftentimes building on existing strengths, programs and community attributes. Building adaptive capacity requires effective communication between communities, other orders of government and researchers. This involves both the two-way transfer of knowledge and the development of tools and other resources to assist regional and local decision-making. The concept and goals of building adaptive capacity need to be conveyed, as does the appropriate information to support improved resource, community and ecosystem planning. In some cases, more information is needed; in others, it is the access to, and communication of, the information that needs to be improved. For example, more research on impacts and adaptation in economic sectors, especially with respect to extreme events, would be useful, as would improved monitoring of key climate elements and environmental variables (e.g. glaciers, groundwater, stream gauging, coastal water levels and erosion/sedimentation, oceanography, floodplain hazard mapping, wildfires and pest spread).

The development of methods and tools by which this information can be disseminated and used is as important as expanding the existing knowledge base. The crucial link is to make the information accessible, by delivering it in a context and language that resonate with the issues and concerns of planners and engineers, resource managers and industry, and leaders of local governments and First Nations. In other words, those most directly responsible for implementing the adaptation.

Finally, it is important to further explore and understand the social and cultural underpinnings of local governance, in particular the makeup and function of local institutions, such as municipal governments, regional districts and First Nations councils, planning and health authorities, engineering departments and resource management bodies. Local and regional interests, and the institutions and organizations that support them, provide the context into which adaptation policies and plans will be introduced and implemented. Understanding how local institutions are set up and how they 'work' within the local and regional environment is a crucial element that will influence the uptake of new information and knowledge, and ultimately determine the success or failure of proactive adaptation.

# REFERENCES

Abeysirigunawardena, D.S. and Walker, I.J. (in press): Sea level response to climate variability and change in northern British Columbia; Atmosphere-Ocean.

Agee, J.K. (1993): Fire ecology of Pacific northwest forests; Island Press, Washington, DC, 490 p.

Ahern, M., Kovats, R.S., Wilkinson, P., Few, R. and Matthies, F. (2005): Global health impacts of floods: epidemiologic evidence; Epidemiologic Reviews, v. 27, p. 36–47.

Alexander, C.A.D., Symonds, B. and Hyatt, K., editors (2005): The Okanagan fish/water management tool v.1.0.001: guidelines for apprentice water managers; unpublished report prepared for the Canadian Okanagan Basin Technical Working Group, Kamloops, BC and Douglas County Public Utility District No. 1, East Wenatchee, Washington, 114 p.

Allan, J.C. and Komar, P.D. (2002): Extreme storms on the Pacific northwest coast during the 1997–8 El Niño and 1998–9 La Niña; Journal of Coastal Research, v. 18, p. 175–193.

Allen, D.M. (2004): Determining the origin of groundwater using stable isotopes of 18O, 2H and 34S; Ground Water, v. 42, no. 1, p. 17–31.

American Meteorological Society (2001): Statement on seasonal to interannual climate prediction; Bulletin of the American Meteorological Society, v. 82, p. 701.

Andrusak, H., Matthews, S., McGregor, I., Ashley, K., Wilson, G., Vidmanic, L., Stockner, J., Sebastian, D., Scholten, G., Woodruff, P., Cassidy, P., Webster, J., Rood, K. and Kay, A. (2002): Okanagan Lake Action Plan Year 6 (2001) Report; BC Ministry of Water, Land and Air Protection, Fisheries Management Branch, Fisheries Project Report No. RD 96.

Anonymous (1974): Canada–British Columbia Okanagan Basin Agreement; BC Water Resources Service, Victoria, BC, summary report of the consultative board including the comprehensive framework plan, 49 p.

Barnett, J. (2001): Adapting to climate change in Pacific Island countries: the problem of uncertainty; World Development, v. 29, no. 6, p. 977–993.

Barnett, T.P., Adams, J.C. and Lettenmaier, D.P. (2005): Potential impacts of a warming climate on water availability in snow-dominated regions; Nature, v. 438, p. 303–309.

Barrie, J.V. and Conway, K.W. (2002): Rapid sea level changes and coastal evolution on the Pacific margin of Canada; Journal of Sedimentary Geology, v. 150, p.171–183.

Baxter, D. and Ramlo, A. (2002): Resource dependency: the spatial origins of British Columbia's economic base; The Urban Futures Institute, Vancouver, BC, 30 p.

BC Centre for Disease Control (2005): Health advisory (June 5, 2005): fungal infection found in Vancouver Coastal and Fraser health regions; BC Centre for Disease Control, Vancouver, BC, 2 p., <http://www.cher.ubc.ca/Cryptococcus/PDFs/cryptococcal_advisory_june2_2005.pdf>, [accessed May 16, 2007].

BC Council of Tourism Associations (2004): BC's Solicitor General allays forest fire concerns; BC Council of Tourism Associations, Tourism News Archive, August 2004, Vancouver, BC, <http://www.cotabc.com/news/tourism_news_archive.aspx?year=2004&month=8>, [accessed May 16, 2007].

BC Hydro (2004): Committee report: Peace Water Use Plan; BC Hydro, Vancouver, BC, 14 p., executive summary available at <http://www.bchydro.com/environment/wateruse/wateruse30860.html>, [accessed May 16, 2007].

BC Hydro (2006): 2006 integrated electricity plan and long term acquisition plan; BC Hydro, Vancouver, BC, 396 p., <http://www.bchydro.com/rx_files/info/info43514.pdf>, [accessed May 10, 2007].

BC Ministry of Agriculture and Lands (1993): Land and resource management planning: a statement of principles and process; BC Ministry of Agriculture and Lands, Integrated Land Management Bureau, Integrated Resource Planning Committee, 1 p., <http://ilmbwww.gov.bc.ca/lup/policies_guides/lrmp_policy/stmt.htm>, [accessed May 16, 2007].

BC Ministry of Agriculture and Lands (2002): British Columbia's fisheries and aquaculture sector, 2002 edition; BC Ministry of Agriculture and Lands, Fisheries Statistics, <www.agf.gov.bc.ca/fish_stats/statistics.htm>, [accessed May 16, 2007].

BC Ministry of Agriculture and Lands (2004): An overview of the British Columbia grape industry; BC Ministry of Agriculture and Lands, December 2004, 35 p., <www.agf.gov.bc.ca/grape/publications/documents/overview_grapes_dec2004.pdf>, [accessed May 16, 2007].

BC Ministry of Agriculture and Lands (2005a): About the agriculture industry: industry significance…some facts; BC Ministry of Agriculture and Lands, <http://www.agf.gov.bc.ca/aboutind/somefact.htm>, [accessed May 16, 2007].

BC Ministry of Agriculture and Lands (2005b): Fast stats agriculture and food; BC Ministry of Agriculture and Lands, Policy and Economics Branch, 32 p., <http://www.agf.gov.bc.ca/stats/index.htm>, [accessed May 16, 2007].

BC Ministry of Energy, Mines and Petroleum Resources (2006): Energy Efficiency Act; BC Ministry of Energy Mines and Petroleum Resources, <http://www.em.gov.bc.ca/AlternativeEnergy/EnergyEfficiency/Energy_Efficiency_Act.htm>, [accessed May 18, 2007].

BC Ministry of Energy, Mines and Petroleum Resources (2007): BC energy plan: a vision for clean energy leadership; BC Ministry of Energy Mines and Petroleum Resources, 40 p., <http://www.energyplan.gov.bc.ca/PDF/BC_Energy_Plan.pdf>, [accessed May 18, 2007].

BC Ministry of Environment (1997a): Salmon aquaculture review — report of the Environmental Assessment Office, Volume 1; BC Ministry of Environment, Environmental Assessment Office, 311 p., <http://www.eao.gov.bc.ca/epic/output/html/deploy/epic_document_20_6045.html>, [accessed May 18, 2007].

BC Ministry of Environment (1997b): Salmon Aquaculture Review report — First Nations perspectives, Volume 2; BC Ministry of Environment, Environmental Assessment Office, 87 p., <http://www.eao.gov.bc.ca/epic/output/html/deploy/epic_document_20_6046.html>, [accessed May 18, 2007].

BC Ministry of Environment (1998): Habitat atlas for wildlife at risk, South Okanagan and Lower Similkameen; *in* Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, BC, February 15–19, 1999, (ed.) L.M. Darling; BC Ministry of Environment, Lands and Parks and University College of the Cariboo, Kamloops, BC, v. 2, 520 p., <http://wlapwww.gov.bc.ca/sir/fwh/wld/atlas/introduction/intro_index.html>, [accessed May 18, 2007].

BC Ministry of Environment (2004): Weather, climate and the future: BC's plan; BC Ministry of Environment, 42 p., <http://www.env.gov.bc.ca/air/climate/cc_plan/pdfs/bc_climatechange_plan.pdf>, [accessed May 18, 2007].

BC Ministry of Environment (2006): British Columbia's coastal environment: 2006; BC Ministry of Environment, <http://www.env.gov.bc.ca/soe/bcce/>, [accessed May 18, 2007].

BC Ministry of Environment, Lands and Parks (1993): Groundwater management; in Stewardship of the Water of British Columbia: A Review of British Columbia's Water Management Policy and Legislation, Section 1, BC Ministry of Environment, Lands and Parks.

BC Ministry of Forests (2005): MPB salvage, hydrology recommendations: recommended operational procedures to address hydrological concerns; BC Ministry of Forests, 7 p., <http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/Hydrological%20Recommendations%20Dec%203%202004.pdf>, [accessed May 18, 2007].

BC Ministry of Forests and Range (2006): Preparing for climate change: adapting to impacts on British Columbia's forest and range resources; BC Ministry of Forests and Range, 94 p., <http://www.for.gov.bc.ca/mof/Climate_Change/Preparing_for_Climate_Change.pdf>, [accessed May 18, 2007].

BC Ministry of Forests and Range (2007): 2006 summary of forest health conditions in British Columbia; BC Ministry of Forests and Range, 73 p., <http://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2006/Aer_OV_final.pdf>, [accessed May 9, 2007].

BC Ministry of Health (2004): Healthy British Columbia: British Columbia's report on nationally comparable health indicators; BC Ministry of Health, 75 p., <http://www.healthservices.gov.bc.ca/cpa/publications/pirc_2004.pdf>, [accessed May 18, 2007].

BC Ministry of Health (2005): BC Health files: hantavirus pulmonary syndrome (HPS); BC Ministry of Health, HealthFile #36, July 2005, 2 p., <http://www.bchealthguide.org/healthfiles/hfile36.stm>, [accessed May 18, 2007].

BC Ministry of Health Planning and Ministry of Health Services (2001): Action plan on safe drinking water in British Columbia; BC Ministry of Health Planning and Ministry of Health Services, 12 p., <http://www.healthservices.gov.bc.ca/cpa/publications/safe_drinking_printcopy.pdf>, [accessed May 18, 2007].

BC Ministry of Health Services (2004): Air quality in British Columbia, a public health perspective; BC Ministry of Health Services, Provincial Health Officer's Annual Report, 2003, 137 p., <http://www.healthservices.gov.bc.ca/pho/pdf/phoannual2003.pdf>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (1997): 1996 census profile; BC Ministry of Labour and Citizens' Services, BC Stats, 16 p., <http://www.bcstats.gov.bc.ca/data/dd/c96drdat.pdf>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2002): British Columbia's fisheries and aquaculture sector; BC Ministry of Labour and Citizens' Services, BC Stats, 103 p., <http://www.bcstats.gov.bc.ca/data/bus_stat/busind/fish.asp>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2004b): Quick facts about British Columbia; BC Ministry of Labour and Citizens' Services, BC Stats, 12 p., <http://www.bcstats.gov.bc.ca/data/qf.pdf>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2005a): British Columbia population forecast – 06/12, Table 1: summary statistics; BC Ministry of Labour and Citizens' Services, BC Stats, <http://www.bcstats.gov.bc.ca/DATA/pop/pop/project/bctab1.asp>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2005b) Tourism industry monitor annual 2005; BC Ministry of Labour and Citizens' Services, BC Stats, 7 p., <www.bcstats.gov.bc.ca/data/bus_stat/busind/tourism/timcurr.pdf>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2005c): 2001 census profile of British Columbia's regions: Central Okanagan Regional District; BC Ministry of Labour and Citizens' Services, BC Stats, 18 p., <http://www.bcstats.gov.bc.ca/data/cen01/profiles/59035000.pdf>, [accessed May 18, 2007].

BC Ministry of Labour and Citizens' Services (2006): A guide to the BC economy and labour market; BC Ministry of Labour and Citizens' Services, BC Stats, <http://www.guidetobceconomy.org/welcome.htm>, [accessed May 18, 2007].

BC Ministry of Small Business and Economic Development and Ministry of Transportation (2005): British Columbia ports strategy; BC Ministry of Small Business and Economic Development and Ministry of Transportation, 34 p., <http://www.gov.bc.ca/ecdev/down/bc_ports_strategy_sbed_mar_18_05.pdf>, [accessed May 18, 2007].

BC Ministry of Water, Land and Air Protection (2002): Indicators of climate change for British Columbia; BC Ministry of Water, Land and Air Protection, 50 p., <http://www.env.gov.bc.ca/air/climate/indicat/pdf/indcc.pdf>, [accessed May 18, 2007].

BC Statutes and Regulations (2001): Chapter 9; in Drinking Water Protection Act [SBC 2001]; BC Statutes and Regulations, <http://www.qp.gov.bc.ca/statreg/stat/D/01009_01.htm>, [May 18, 2007].

BC Sustainable Energy Association (2006): Solar hot water program; BC Sustainable Energy Association, <http://www.solarbc.org>, [accessed May 18, 2007].

Beamish, R.J. and Noakes, D.J. (2004): Global warming, aquaculture, and commercial fisheries; *in* Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities (Second Edition), (ed.) K.M. Leber, S. Kitada, H.L. Blankenship and T. Svasand; Blackwell Publishing Ltd., Oxford, United Kingdom, p. 25–47.

Beamish, R.J., Pearsall, I.A. and Healey, M.C. (2003): A history of the research on the early marine life of Pacific salmon off Canada's Pacific coast; North Pacific Anadromous Fish Commission Bulletin, v. 3, p. 1–40.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A., McClain, C.R., Sarmiento, J.L., Feldman, G.C., Milligan, A.J., Falkowski, P.A., Letelier, R.M. and Boss, E.S. (2006): Climate-driven trends in contemporary ocean productivity; Nature, v. 444, p. 752–755.

Belliveau, S., Bradshaw, B., Smit, B., Reid, S., Ramsey, D., Tarleton, M. and Sawyer, B. (2006a): Farm-level adaptation to multiple risks: climate change and other concerns; University of Guelph, Department of Geography, Occasional Paper 27, 99 p., <http://adaptation.nrcan.gc.ca/projdb/pdf/93_e.pdf>, [accessed August 2, 2007].

Belliveau, S., Smit, B. and Bradshaw, B. (2006b): Multiple exposures and dynamic vulnerability: evidence from the grape industry in the Okanagan Valley, Canada; Global Environmental Change, v. 16, p. 364–378.

Bezener, A., Dunn, M., Richardson, H., Dyer, O., Hawes, R. and Hayes, T. (2004): South Okanagan–Similkameen conservation program: a multi-partnered, multi-species, multi-scale approach to conservation of species at risk; *in* Proceedings of the Species at Risk 2004 Pathways to Recovery Conference, March 2–6, 2004, Victoria, BC, (ed.) T.D. Hooper; Pathways to Recovery Conference Organizing Committee, Victoria, BC, 10 p., <http://www.llbc.leg.bc.ca/Public/PubDocs/bcdocs/400484/bezener_edited_final_feb_8.pdf>, [accessed May 18, 2007].

Biondi F., Gershunov A. and Cayan D.R. (2001): North Pacific decadal climate variability since 1661; Journal of Climate, v. 14, no. 1, p. 5–10.

Boldt, J., Batchelder, H., Crawford, W., Hollowed, A., King, J., McFarlane, G., Mueter, F., Perry, I. and Schweigert, J. (2005): Appendix 3: recent ecosystem changes in the Gulf of Alaska; *in* Report of the Study Group on Fisheries and Ecosystem Response to Recent Regime Shifts, (ed.) J. King; North Pacific Marine Science Organization (PICES), Sydney, BC, Scientific Report 28, 162 p., <http://www.pices.int/publications/scientific_reports/Report28/Rep_28_default.aspx>, [May 18, 2007].

Bond, N.A. and Harrison, D.E. (2000): The Pacific Decadal Oscillation, air-sea interaction and central north Pacific winter atmospheric regimes; Geophysical Research Letters, v. 27, p. 731–734.

Bonsal, B.R. and Prowse, T.D. (2003): Trends and variability in spring and autumn 0°C isotherm dates over Canada; Climatic Change, v. 57, p. 341–358.

Bonsal, B.R., Zhang, X., Vincent, L.A. and Hogg, W.D. (2001): Characteristics of daily and extreme temperatures over Canada; Journal of Climate, v. 14, p. 1959–1976.

Bowen, P.A., Bogdanoff, C.P., Estergaard, B.F., Marsh, S.G., Usher, K.B., Smith, C.A.S. and Frank, G. (2006): Geology and wine 10: use of geographic information system technology to assess viticulture in the Okanagan and Similikameen valleys, British Columbia; Geoscience Canada, v. 32, p. 161–176.

Brauer, M., Hoek, G., Van Vliet, P., Meliefste, K., Fischer, P., Wijga, A., Koopman, L., Neijens, H.J., Gerritsen, J., Kerkhof, M., Heinrich, J., Bellander, T. and Brunekreef, B. (2002): Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children; American Journal of Respiratory and Critical Care Medicine, v. 166, p. 1092–1098.

Brauer, M., Petkau, J., Vedal, S. and White, R. (2003): Air pollution and daily mortality in a city with low levels of pollution; Environmental Health Perspectives, v. 111, p. 45–51.

Bremmer, L. and Bremmer, J. (2004): BC grape acreage report — August 20, 2004; unpublished report prepared by Mount Kobau Wine Services for the BC Grapegrowers Association, <http://www.grapegrowers.bc.ca/winecrop.shtml>, [May 18, 2007].

Brenner, N. and Theodore, N. (2002): Preface: from the new localism to the spaces of neoliberalism; Antipode, v. 34, p. 341–347.

Brown, K.J. and Hebda, R.J. (2002): Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada; Canadian Journal of Forest Research, v. 32, p. 353–372.

Brown, K.J. and Hebda, R.J. (2003): Temperate rainforest connections disclosed through a late-Quaternary vegetation, climate, and fire history investigation from the mountain hemlock zone on southern Vancouver Island, British Columbia, Canada; Review of Palaeobotany and Palynology, v. 123, p. 247–269.

Brubaker, L. (1988): Vegetation history and anticipating future vegetation change; *in* Ecosystem Management for Parks and Wilderness, (ed.) J.K. Agee and D.R. Johnson; University of Washington Press, Seattle, Washington, p. 41–61.

Bruce, J.P. (2003): Implications of climate change for flood damage reduction in Canada; Proceedings of the 3rd Canadian Conference on Geotechnique and Natural Hazards, June 8–10, 2003, Geohazards 2003; Geotechnical Society, Edmonton, Alberta, p. 29-34.

Brugman, M.M., Pietroniro, A. and Shi, J. (1996): Mapping alpine snow and ice using Landsat™ and SAR imagery at Wapta icefield; Canadian Journal of Remote Sensing, v. 22, p. 127–136.

Buckland, J. and Rahman, M. (1999): Community-based disaster management during the 1997 Red River flood in Canada; Disasters, v. 23, no. 2, p. 174–191.

Bull, C. (1999): Fisheries habitat in the Okanagan River, phase 2: investigation of selected options; unpublished report prepared for Douglas County Public Utility, District No. 1 of Washington State, Wenatchee, Washington.

Burnett, R.T., Cakmak, S. and Brook, J.R. (1998): The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities; Canadian Journal of Public Health, v. 89 no. 3, p. 152–156.

Burnett, R.T., Chen, Y., Krewski, D., Liu, K. and Shi, Y. (2003): Association between gaseous ambient air pollutants and adverse pregnancy outcomes in Vancouver, Canada; Environmental Health Perspectives, v. 111, p. 1773–1778.

Burton, B., Gu, L. and Yin, Y.Y. (2005): Overview of vulnerabilities of coastally-influenced conveyance and treatment infrastructure in Greater Vancouver to climate change: identification of adaptive responses; *in* EWRI 2005: Impacts of Global Climate Change, (ed.) R. Walton; Proceedings of the World Water and Environment Conference, May 15–19, 2005, Anchorage Alaska; American Society of Civil Engineering, Environmental and Water Resources Institute, doi: 10.1061/40792(173)79.

Burton, I., Kates, R.W. and White, G.F. (1978): The Environment as Hazard; Oxford University Press, New York, New York, 258 p.

Butler, R.W. (1999): Winter abundance and distribution of shorebirds and songbirds on farmlands on the Fraser River Delta, British Columbia, 1989–1991; Canadian Field-Naturalist, v. 113, no. 3, p. 390–395.

Cammell, M.E. and Knight, J.D. (1992): Effects of climatic change on the population dynamics of crop pests; Advances in Ecological Research, v. 22, p. 117–162.

Canadian Association of Petroleum Producers (2005): British Columbia's oil and natural gas industry; Canadian Association of Petroleum Producers, Calgary, Alberta, 2 p., <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=84443>, [accessed May 18, 2007].

Canadian Association of Petroleum Producers (2006): Industry facts and information, western Canada, British Columbia statistics for the past eight years; Canadian Association of Petroleum Producers Calgary, Alberta, 1 p., <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=34089> [accessed May 18, 2007].

Capital Regional District Water Services (2004): 2004 review of the strategic plan for water management; Capital Regional District Water Services, Victoria, BC, 161 p.

Capital Regional District Water Services (2007): The need to conserve water; how does climate affect our water use?; Capital Regional District Water Services, Victoria, BC, <http://www.crd.bc.ca/water/conservation/images/demand3.gif>, [accessed May 19, 2007].

Caprio, J.M. and Quamme, H.A. (1999): Weather conditions associated with apple production in the Okanagan Valley of British Columbia; Canadian Journal of Plant Science, v. 79, no. 1, p. 129–137.

Caprio, J.M. and Quamme, H.A. (2002): Weather conditions associated with grape production in the Okanagan Valley of British Columbia and potential impact of climate change; Canadian Journal of Plant Science, v. 82, no. 4, p. 755–763.

Caprio, J.M. and Quamme, H.A. (2006): Influence of weather on apricot, peach and sweet cherry production in the Okanagan Valley of British; Canadian Journal of Plant Science, v. 86, p. 259–267.

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

Cashore, B., Hoberg, G., Howlett, M., Rayner, J. and Wilson J. (2001): In Search of Sustainability: British Columbia Forest Policy in the 1990s; University of British Columbia Press, Vancouver, BC, 340 p.

Casola, J.H., Kay, J.E., Snover, A.K., Norheim, R.A. and Whitely Binder, L.C. (2005): Climate impacts on Washington's hydropower, water supply, forests, fish and agriculture; unpublished report prepared for King County, Washington by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington, <http://www.cses.washington.edu/db/pdf/kc05whitepaper459.pdf>, [accessed May 18, 2007].

Chang, A.S. and Patterson, R.T. (2005): Climate shift at 4400 years BP: evidence from high-resolution diatom stratigraphy, Effingham Inlet, British Columbia, Canada; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 226, no. 2–3, p. 72–92.

Chang, A.S., Patterson, R.T. and McNeely, R. (2003): Seasonal sediment and diatom record from the late Holocene laminated sediments, Effingham Inlet, British Columbia, Canada; Palaios, v. 18, p. 477–494.

Changnon S.A., Huff, F.A. and Hsu, C.F. (1988): Relations between precipitation and shallow groundwater in Illinois; Journal of Climate, v. 1, no. 12, p. 1239–1250, <http://ams.allenpress.com/archive/1520-0442/1/12/pdf/i1520-0442-1-12-1239.pdf>, [accessed May 18, 2007].

Cheng, J.D. (1989): Streamflow changes after clear-cut logging of a pine beetle–infested watershed in southern British Columbia, Canada; Water Resources Research, v. 25, p. 449–456.

Clague, J.J. and Bornhold, B.D. (1980): Morphology and littoral processes of the Pacific coast of Canada; *in* The Coastline of Canada, Littoral Processes and Shore Morphology, Proceedings of a Conference held in Halifax, May 1–3, 1978, (ed.) S.B. McCann; Geological Survey of Canada, Paper 80-10, p. 339–380.

Clark, G.E., Moser, S.C., Ratick, S.J., Dow, K., Meyer, W.B., Emani, S., Jin, W., Kasperson, J.X., Kasperson, R.E. and Schwarz, H.E. (1998): Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA, USA; Mitigation and Adaptation Strategies for Global Change, v. 3, p. 59–82, <http://nome.colorado.edu/HARC/Readings/Clark.pdf>, [accessed May 18, 2007].

Clarke, W.G. and Hare, S.R. (2002): Effects of climate and stock size on recruitment and growth of Pacific halibut; North American Journal of Fisheries Management, v. 22, p. 852–862.

Climate Impacts Group (2006): Impacts of natural climate variability on Pacific Northwest climate; Climate Impacts Group, <http://www.cses.washington.edu/cig/pnwc/clvariability.shtml> and <http://www.cses.washington.edu/cig/pnwc/pnwc.shtml>, [accessed May 18, 2007].

Cohen, S.J. (1997): What if and so what in northwest Canada: could climate change make a difference to the future of the Mackenzie Basin?; Arctic, v. 50, no. 4, p. 293–307.

Cohen, S.J. and Kulkarni, T., editors (2001): Water management and climate change in the Okanagan Basin; Environment Canada and University of British Columbia, 75 p., <http://adaptation.nrcan.gc.ca/projdb/pdf/46_e.pdf>, [accessed May 18, 2007].

Cohen, S.J., Merritt, W.S., Alila, Y., Barton, M. and Taylor, B. (2003): Exploring impacts of climate change on the hydrology of the Okanagan Basin; *in* Proceedings of Canadian Water Resources Association, 56th Annual Conference, Vancouver, BC, 179 p.

Cohen, S.J., Miller, K.A., Hamlet, A.F. and Avis, W. (2000): Climate change and resource management in the Columbia River basin; Water International, v. 25, no. 2, p. 253–272.

Cohen, S.J., Neilsen, D., Smith, S., Neale, T., Taylor, B., Barton, M., Merritt, W.S., Younes, A., Shepherd, P., McNeill, R., Tansey, J., Carmichael, J. and Langsdale, S. (2006): Learning with local help: expanding the dialogue on climate change and water management in the Okanagan Region, British Columbia, Canada; Climatic Change, v. 75 p. 331–358.

Cohen, S.J., Nielsen, D. and Welbourn, R. (2004): Expanding the Dialogue on Climate Change and Water Management in the Okanagan Basin, British Columbia; Environment Canada, Agriculture and Agri-Food Canada and University of British Columbia, 230 p.

Coleman, J.S. (1988): Social capital in the creation of human capital; in Organizations and Institutions: Sociological and Economic Approaches to the Analysis of Social Structure; American Journal of Sociology, v. 94 (supplement), p. S95–S120.

Columbia Mountain Institute for Applied Ecology (2003): Climate change in the Columbia basin; Proceedings of a workshop held January 17-18, 2003, Cranbrook, BC, 102 p., <http://www.cmiae.org/pdf/ClimateChange2003.pdf>, [accessed May 18, 2007].

Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (1996): Upstream: Salmon and Society in the Pacific Northwest; National Academies Press, Washington, DC, 452 p.

Conner, T. (2005): Social vulnerability and adaptive capacity to climate change impacts: identifying attributes in two remote coastal communities on Haida Gwaii, British Columbia; M.A. thesis, Department of Geography, University of Victoria, Victoria, BC, 207 p.

Cooke, S.J., Hinch, S.G., Farrell, A.P., Lapointe, M.F., Jones, S.R.M., Macdonald, J.S., Patterson, D.A., Healey, M.C. and Van Der Kraak, G. (2004): Abnormal migration and high en route mortality of sockeye salmon in the Fraser River, British Columbia; Fisheries, v. 29, p. 22–33.

Crabbe, C. (2003): France caught cold by heatwave; Bulletin of the World Health Organization, v. 81, no. 10, p. 773–774, <http://www.who.int/bulletin/volumes/81/10/773-775%20(news).pdf>, [accessed May 18, 2007].

Craig-Smith, J., Tapper, R. and Font, X. (2006): The coastal and marine environment; *in* Tourism and Global Environmental Change: Ecological, Social, Economic and Political Interrelationships, (ed.) S. Gössling and C.M. Hall; Routledge, London, United Kingdom, p. 107–127.

Crawford, W.R., Cherniawkey, J., Foreman, M. and Chandler, P. (1999): El Niño sea level signal along the west coast of Canada; *in* Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and its Marginal Seas; North Pacific Marine Science Organization (PICES), Scientific Report 10, 4 p., <http://www.pices.int/publications/scientific_reports/Report10/default.aspx>, [accessed May 18, 2007].

Cumming, S.G. and Burton, P.J. (1996): Phenology-mediated effects of climatic change on some simulated British Columbia forests; Climatic Change, v. 34, p. 213–222.

Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J. and Wotton, B.M. (2001): Climate change and forest disturbances; BioScience, v. 51, p. 723–734.

Daly, C., Gibson, W.P., Taylor, G.H., Johnson, G.L. and Pasteris, P. (2002): A knowledge-based approach to the statistical mapping of climate; Climate Research, v. 22, p. 99–113.

Davidson, D., Williamson, T. and Parkins, J. (2003): Understanding climate change risk and vulnerability in northern forest-based communities; Canadian Journal of Forest Research, v. 33, p. 2252–2261.

Degg, M.R. and Homan, J. (2005): Earthquake vulnerability in the Middle East; Geography, v. 90, p. 54–66.

Dewar, K. (2005): Everyone talks about the weather; *in* Tourism, Recreation and Climate Change, (ed.) C.M. Hall and J. Higham; Channel View, Clevedon, United Kingdom, p. 234–246.

Dingler, J.R. and Reiss, T.E. (2001): Changes to Monterey Bay beaches from the end of the 1982–83 El Nino through the 1997–98 El Nino; Marine Geology, v. 181, no. 1, p. 249–263.

Dobson Engineering Ltd. (2004): Chase Creek hydrologic assessment: impact of mountain pine beetle infestations on peak flows (including application of the Ministry of Forests' Extension Note 67); Riverside Forest Products Limited, Tolko Industries Ltd. and BC Forest Service, 43 p.

Dods, P. and Copes, R. (2005): Wood smoke, forest fires and PM2.5 in British Columbia; BC Medical Journal, v. 47, no. 5, p. 132–133.

Dolan, A.H. and Walker, I.J. (2007): Understanding vulnerability of coastal communities to climate change related risks; Journal of Coastal Research, Special Issue 39, p. 1317–1324.

Drebot, M.A., Artsob, H. and Werker, D. (2000): Hantavirus pulmonary syndrome in Canada, 1989–1999; Canada Communicable Disease Report, v. 26-08, p. 65–69, <http://www.phac-aspc.gc.ca/publicat/ccdr-rmtc/00vol26/dr2608ea.html>, [accessed May 18, 2007].

Dry, P.R., Loveys, B.R., McCarthy, M.G. and Stoll, M. (2001): Strategic irrigation management in Australian vineyards; International Journal of Vine and Wine Sciences, v. 35, p. 129–139.

Dyer, D. (2006): What can a community do?; *in* Proceedings, Communities and Climate Change Workshop: Planning for Impacts and Adaptations, Prince George, British Columbia, May 17, 2006, (comp.) C. Wainwright and K. Zimmerman; McGregor Model Forest Association, <http://www.mcgregor.bc.ca/downloads/Proceedings.pdf>, [accessed May 18, 2007].

Dyer, J.M. (1995): Assessment of climatic warming using a model of forest species migration; Ecological Modelling, v. 79, p. 199–219.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S., Karl, T.R. and Mearns, L.O. (2000): Climate extremes: observations, modeling and impacts; Science, v. 289, no. 5487, p. 2068–2074.

Elner, R.W., Beninger, P.G., Jackson, D.L. and Potter, T.M. (2005): Evidence of a new feeding mode for in western sandpiper and dunlin based on bill and tongue morphology and ultrastructure; Marine Biology, v. 146 no. 6, p. 1223–1234.

Engelthaler, D.M., Mosley, D.G., Cheek, J.E., Levy, C.E., Komatsu, K.K., Ettestad, P., Davis, T., Tanda, D.T., Miller, L., Frampton, J.W., Porter, R. and Bryan, R.T. (1999): Climatic and environmental patterns associated with hantavirus pulmonary syndrome, Four Corners region, United States; Emerging Infectious Diseases, v. 5, p. 87–94.

Enns, S., Malinick, T. and Matthews, R. (in press): It's not only who you know, it's also where they are: using the position generator to investigate the structure of access to socially embedded resources; *in* Social Capital: Advances in Research, (ed.) N. Lin and B.H. Erickson; Oxford University Press, New York, New York.

Environment Canada (2003): El Niño Canadian effects: Pacific coast; Environment Canada, <http://www.msc.ec.gc.ca/education/elnino/canadian/region/index_mean_e.cfm>, [accessed May 18, 2007].

Environment Canada (2004): Threats to water availability in Canada; Environment Canada, National Water Research Institute, <http://www.nwri.ca/threats2full/intro-e.html>, [accessed May 18, 2007].

Fankhauser, S. and Tol, R.S.J. (1997): The social costs of climate change: the IPCC second assessment report and beyond; Mitigation and Adaptation Strategies for Global Change, v. 1, no. 4, p. 385–403.

Fisheries and Oceans Canada (2001): Fish stocks of the Pacific coast; Fisheries and Oceans Canada, 162 p., <http://www-comm.pac.dfo-mpo.gc.ca/publications/speciesbook/PacificFishStocks.pdf>, [accessed May 18, 2007].

Fisheries and Oceans Canada (2006a): State of the Pacific Ocean 2005; Fisheries and Oceans Canada, Canadian Science Advisory Secretariat (CSAS), Ocean Status Report 2006/001, 70 p., <http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/StateofOceans2005fnl.pdf>, [accessed May 18].

Fisheries and Oceans Canada (2006b): Pacific Region, Integrated Fisheries Management Plan, Salmon, Southern BC, June 1, 2006–May 31, 2007; Fisheries and Oceans Canada, 113 p., <http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/plans06/Salmon/southcoast/Salmon%20IFMP.SC.2006.pdf>, [accessed May 18, 2007].

Fisheries and Oceans Canada (2006c): Pacific Region, Integrated Fisheries Management Plan, Salmon, Northern BC, June 1, 2006–May 31, 2007; Fisheries and Oceans Canada, 87 p., <http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/plans06/Salmon/northcoast/Salmon%20IFMP.NC.2006.pdf>, [accessed May 18, 2007].

Flannigan, M.D, Campbell, I., Wotton, M., Carcaillet, C., Richard, P. and Bergeron, Y. (2001): Future fire in Canada's boreal forest: paleoecology results and general circulation model — regional climate model simulations; Canadian Journal of Forest Research, v. 31, p. 854–864.

Flannigan, M.D., Logan, K.A., Amiro, B.D., Skinner, W.R. and Stocks, B.J. (2005): Future area burned in Canada; Climatic Change, v. 72, p. 1–16.

Flato, G.M., Boer, G.L., Lee, W.G., McFarlane, N.A., Ramsden, D., Reader, M.C. and Weaver, A.J. (2000): The Canadian Centre for Climate Modelling and Analysis global coupled model and its climate; Climate Dynamics, v. 16, p. 451–467.

Fleming, S.W. (2005): Comparative analysis of glacial and nival streamflow regimes with implications for lotic habitat quantity and fish species richness; Water Research and Applications, v. 21, p. 363–379.

Fleming, S.W. and Clark, G.K.C. (2005): Attenuation of high-frequency interannual streamflow variability by watershed glacial cover; ASCE Journal of Hydraulic Engineering, v. 131, no. 7, p. 615–618.

Fleming, S.W., Moore, R.D. and Clarke, G.K.C. (2006): Glacier-mediated streamflow teleconnections to the Arctic Oscillation; International Journal of Climatology, v. 26, p. 619–636.

Ford, J. and Smit, B. (2004): A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change; Arctic, v. 57 no. 4, p. 389–400.

Forest Practices Board of BC (2007): The effect of mountain pine beetle attack and salvage harvesting on streamflows; Forest Practices Board of British Columbia, Vancouver, BC, Special Investigation FPB/SIR/16, 27 p., <http://www.fpb.gov.bc.ca/news/releases/2007/03.16.07.htm>, [accessed May 11, 2007].

Forest Products Association of Canada (2006): Environmental stewardship: climate change; Forest Products Association of Canada, <http://www.fpac.ca/en/sustainability/stewardship/climate_change.php>, [accessed May 18, 2007].

FortisBC (2006): PowerSense program; FortisBC, <http://www.fortisbc.com/energy_efficiency/about_energy_efficiency.html>, [accessed May 18, 2007].

Frame, T.M., Gunton, T. and Day, J.C. (2004): The role of collaboration in environmental management: an evaluation of land and resource planning in British Columbia; Journal of Environmental Planning and Management, v. 47, no. 1, p. 59–82.

Fraser River Sockeye Public Review Board (1995): Fraser River sockeye 1994: problems and discrepancies; Government of Canada, 131 p.

Frenkel, B. (2005): Vanderhoof climate change: stakeholder study; unpublished report prepared by Avison Management Service Ltd. for Vanderhoof, BC.

Furniss, M.M. and Schenk, J.A. (1969): Sustained natural infestations by the MPB in seven new Pinus and Picea hosts; Journal of Economic Entomology, v. 62, p. 518–519.

Gagné, J., Cocksedge, W., Burton, P., Thomson, A., Titus, B., Winder, R., Berch, S., Tedder, S., Fekete, W., Keefer, M. and Prest, G. (2004): Integrating non-timber forest products into forest planning and practices in British Columbia; Forest Practices Board, Victoria, BC, Special Report 19, 33 p., <http://www.fpb.gov.bc.ca/SPECIAL/reports/SR19/SR19.pdf>, [accessed May 18, 2007].

Gardner, J. and Peterson, D. (2003): Making sense of the salmon aquaculture debate: analysis of issues related to netcage salmon farming and wild salmon in British Columbia; unpublished report prepared for the Pacific Fisheries Resource Conservation Council, Vancouver, BC, 139 p., <http://www.fish.bc.ca/files/SalmonAquaculture-MakingSenseDebate_2003_0_Complete.pdf>, [accessed May 18, 2007].

Garibaldi, A. and Turner, N. (2004): Cultural keystone species: implications for ecological conservation and restoration; Ecology and Society, v. 93, no. 3, <http://www.ecologyandsociety.org/vol9/iss3/art1/>, [accessed May 18, 2007].

Gavin, D.G., McLachlan, J.S., Brubaker, L.B. and Young, K.A. (2001): Postglacial history of subalpine forests, Olympic Peninsula, Washington, USA; The Holocene, v. 11, p. 177–188.

Gedalof, Z. and Smith, D.J. (2001): Interdecadal climate variability and regime-scale shifts in Pacific North America; Geophysical Research Letters, v. 28, p. 1515–1518.

Gedalof, Z., Mantua, N.J. and Peterson, D.L. (2002): A multi-century perspective of variability in the Pacific Decadal Oscillation: new insights from tree rings and coral; Geophysical Research Letters, v. 29, doi:10.1029/2002GL015824.

Gedalof, Z., Peterson, D.L. and Mantua, N.J. (2004): Columbia River flow and drought since 1750; Journal of the American Water Resources Association, v. 40, p. 1579–1592.

Gedalof, Z., Peterson, D.L. and Mantua, N.J. (2005): Atmospheric, climatic and ecological controls on extreme wildfire years in the northwestern United States; Ecological Applications, v. 15, p. 154–174.

Gershunov, A. and Barnett, T.P. (1998): Interdecadal modulation of ENSO teleconnections; Bulletin of the American Meteorological Society,v. 79, no. 12, p. 2715–2725.

Gerwing, K. and McDaniels, T. (2006): Listening to the Salmon People: coastal First Nations' objectives regarding salmon aquaculture in British Columbia; Society and Natural Resources, v. 19, p. 259–273.

Gillett, N.P., Weaver, A.J., Zweirs, F.W. and Flannigan, M.D. (2004): Detecting the effect of climate change on Canadian forest fires; Geophysical Research Letters, v. 31, L18211, doi:10.1029/2004GL020876.

Glass G.E., Cheek, J.E., Patz, J.A., Shields, T.M., Doyle, T.J., Thoroughman, D.A., Hunt, D.K., Enscore, R.E., Gage, K.L., Irland, C., Peters, C.J. and Bryan, R. (2000): Using remotely sensed data to identify areas at risk for hantavirus pulmonary syndrome; Emerging Infectious Diseases, v. 6, p. 238–247.

Glavin, T. (1996): Dead Reckoning: Confronting the Crisis in Pacific Fisheries; Greystone Books, Vancouver, BC, 181 p.

Goklany, I.M. (1995): Strategies to enhance adaptability: technological change, sustainable growth and free trade; Climatic Change, v. 30, p. 427–449.

Gray, P.A. (2005): Impacts of climate change on diversity in forested ecosystems: some examples; The Forestry Chronicle, v. 81, p. 655–661.

Greater Vancouver Regional District (1999): Livable region strategic plan; Greater Vancouver Regional District, Policy and Planning Department, 35 p., <http://www.gvrd.bc.ca:80/growth/lrsp.htm>, [accessed May 18, 2007].

Greater Vancouver Regional District (2005a): Water: the Greater Vancouver Water District water consumption statistics, 2004 edition; Greater Vancouver Regional District, 66 p., <http://www.gvrd.bc.ca/water/pdfs/ConsumptionStatistics2004.pdf>, [accessed May 18, 2007].

Greater Vancouver Regional District (2005b): Drinking water: quality on tap (drinking water management plan for the GVWD and member municipalities); Greater Vancouver Regional District, 12 p., <http://www.gvrd.bc.ca/water/pdfs/DrinkingWaterManagementPlanA.pdf>, [accessed May 18, 2007].

Greater Vancouver Regional District (2006): GVRD residents are advised of deteriorating water quality; Greater Vancouver Regional District, media release, November 16, 2006, <http://www.gvrd.bc.ca/media/2006/2006-11-16-Media-ReleaseResidentsAdvisedWaterQuality.pdf>, [accessed May 11, 2007].

Greater Vancouver Transportation Authority (2005): 2006 transportation plan; Greater Vancouver Transportation Authority, 99 p., <http://www.translink.bc.ca/files/pdf/plan_proj/2006_Transportation_Plan.pdf>, [accessed May 18, 2007].

Gregory, R., Failing, L. and Arvai, J. (2006): Indicators for climate change at Roberts Bank; unpublished report prepared for Natural Resources Canada, Earth Sciences Sector, 20 p.

Hagerman, S and Dowlatabadi, H. (2006): What! Biodiversity set-asides may not protect against climate change?; University of British Columbia, Institute for Resources, Environment and Sustainability, presentation at Climate Decision Making Center seminar, April 5, 2006, <http://cdmc.epp.cmu.edu/Hadi_spring06.pdf>, [accessed May 23, 2007].

Haida Gwaii–Queen Charlotte Islands Land Use Planning Process Team (2006): Haida Gwaii–Queen Charlotte Islands Land Use Plan recommendations report and agenda; BC Integrated Land Management Bureau, 254 p., <http://ilmbwww.gov.bc.ca/lup/lrmp/coast/qci/docs/fin_LUP_package_Jan26-06.pdf>, [accessed May 18, 2007].

Haines, A. and Patz, J. (2004): Health effects of climate change; Journal of the American Medical Association, v. 291, no. 1, p. 99–103.

Hallin, L. (2001): A guide to the BC economy and labour market; BC Ministry of Labour and Citizens' Services, <http://www.bcstats.gov.bc.ca/pubs/econ_gui.asp>, [accessed May 18, 2007].

Hamann, A. and Wang, T.L. (2005): Models of climate normals for genecology and climate change studies in BC; Agricultural and Forest Meteorology, v. 128, p. 211–221.

Hamann, A., and Wang, T.L. (2006): Potential effects of climate change on ecosystem and tree species distribution in British Columbia; Ecology, v. 87, no. 11, p. 2773–2786.

Hamlet, A.F. (2003): The role of transboundary agreements in the Columbia River basin: an integrated assessment in the context of historical development, climate, and evolving water policy; *in* Climate, Water and Transboundary Challenges in the Americas, (ed.) H. Diaz and B. Morehouse; Kluwer Press, Boston, Massachusetts, p. 263–289.

Hamlet, A.F. and Lettenmaier, D.P. (1999): Effects of climate change on hydrology and water resources in the Columbia River basin; Journal of the American Water Resources Association, v. 35, no. 6, p. 1597–1623.

Hamlet, A.F., Huppert, F.D. and Lettenmaier, D.P. (2002): Economic value of long-lead streamflow forecasts for Columbia river hydropower; American Society of Civil Engineers Journal of Water Resources Planning and Management, v. 128, no. 2, p. 91–101.

Hamon, W.R. (1963): Computation of direct runoff amounts from storm rainfall; International Association of Scientific Hydrology Publication, v. 63, p. 52–62.

Hanlon, N. and Halseth, G. (2005): The greying of resource communities in northern British Columbia: implications for health care delivery in already-underserviced communities; Canadian Geographer, v. 49, no. 1, p. 1–24.

Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D. and Woodward, F.I. (2002): Conservation of biodiversity in a changing climate; Conservation Biology, v. 16, p. 264–268.

Hansen, A.J., Neilson, R.P., Dale, V.H., Flather, C.H., Iverson, L.R., Currie, D.J., Shafer, S., Cook, R. and Bartlein, P.J. (2001): Global change in forests: response of species, communities, and biomes; BioScience, v. 51, no. 9, p. 765–779.

Harding, L.E. and McCullum, E. (1997): Ecosystem response to climate change in British Columbia and Yukon: threats and opportunities for biodiversity; *in* Responding to Global Climate Change in British Columbia and Yukon, (ed.) E. Taylor and B. Taylor; Environment Canada, p. 9.11–9.22.

Hare, S.R. and Mantua, N.J. (2000): Empirical evidence for North Pacific regime shifts in 1977 and 1989; Progress in Oceanography, v. 47, p. 103–145.

Hargreaves, N.B., Ware, D.M. and McFarlane, G.A. (1994): Return of the Pacific sardine Sardinops sagax to the British Columbia coast in 1992; Canadian Journal of Fisheries and Aquatic Sciences, v. 51, p. 460–463.

Harris, S. (2001): Impacts of fish contamination on native American culture; paper presented at Annual Forum on Contaminants in Fish, Chicago, Illinois, United States Environmental Protection Agency, MN Department of Health.

Hayter, R. (2000): Flexible Crossroads: The Restructuring of British Columbia's Forest Economy; University of British Columbia Press, Vancouver, BC, 416 p.

Hebda, R.J. (1997): Impact of climate change on biogeoclimatic zones of British Columbia and Yukon; *in* Responding to Global Climate Change in British Columbia and Yukon, (ed.) E. Taylor and B. Taylor; Environment Canada, p. 13.1–13.15.

Hebda, R.J. (1998): Atmospheric change, forests and biodiversity; Environmental Monitoring and Assessment, v. 49, p. 195–212.

Hebda, R.J. (1999): History of cedars in western North America; *in* Proceedings of the Cedar Symposium: Growing Western Redcedar and Yellow-cypress on the Queen Charlotte Islands / Haida Gwaii, (ed.) G.G. Wiggins; BC Ministry of Forests, p. 5–13.

Hebda, R.J., and Whitlock, C. (1997): Environmental history of the coastal temperate rain forest of northwest North America; *in* The Rain Forests of Home: Profile of a North American Bioregion, (ed.) P.K. Schoonmaker, B. von Hagen and E.C. Wolf; Island Press, Washington, DC, 447 p.

Heinberg, R. (2003): The Party's Over: Oil, War and the Fate of the Industrial Societies; New Society Publishers, Gabriola Island, BC, 320 p.

Hélie, J-F., Peters, D.L., Tattrie, K.R. and Gibson, J.J. (2005): Review and synthesis of potential hydrologic impacts of mountain pine beetle and related harvesting activities in British Columbia; Natural Resources Canada, Canadian Forest Service, Mountain Pine Beetle Initiative, Working Paper 2005-23, 34 p., <http://warehouse.pfc.forestry.ca/pfc/25684.pdf>, [accessed May 18, 2007].

Herbert-Cheshire, L. and Higgins, V. (2004): From risky to responsible: expert knowledge and the governing of community-led development; Journal of Rural Studies, v. 20, p. 289–302.

Hertzman, C., Frank, J. and Evans, R. (1994): Heterogeneities in health status and the determinants of population health; *in* Why Are Some People Healthy and Others Not?, (ed.) R.G. Evans, M.L. Barer, and T.R. Marmor; Aldine de Gruyter, New York, New York, p. 67–92.

Hicks, R.W.B. and von Euw, E.L. (2004): Integrated stormwater management planning process to address climate and land-use changes in urban watersheds in the Greater Vancouver Regional District; *in* Proceedings of the 16th International Conference, Society for Ecological Restoration, August 24–26, 2004, Victoria, BC.

Hill, P.R., editor (in press): Biophysical impacts of sea level rise and changing storm conditions on Roberts Bank; Geological Survey of Canada, Open File.

Hill, P.R., Houser, C., Lintern, D.G., Shaw, A., Solomon, S., Sutherland, T., Levings, C. and Tansey, J. (2004): Sensitivity of the Roberts Bank tidal flats, Vancouver, Canada to climate change and anthropogenic alteration; in Delivering Sustainable Coasts: Connecting Science and Policy, Proceedings of Littoral 2004, Aberdeen, Scotland, September 20–22, 2004; Cambridge Publications, Cambridge, United Kingdom, p. 648–649.

Hoberg, G. (1996): The Politics of Sustainability: Forest Policy in British Columbia; *in* Politics, Policy, and Government in British Columbia, (ed.) R. Carty; University of British Columbia Press, Vancouver, BC, 381 p.

Holman, G. and Nicol, S. (2001): Socio-eonomic and environmental base case: socioeconomic component; Government of British Columbia, Sea-to-Sky Land and Resource Management Plan (LRMP), <http://ilmbwww.gov.bc.ca/lup/lrmp/coast/s2s/reports/base_case_chapters/contents.pdf>, [August 15, 2007].

Hourston, R., Clay, C.H., Burridge, E.W., Lucas, K.C., Johnson, D.R., Heg, H.T., McKinley, W.R., Barnaby, J.T., Fulton, L.A. and Gentry, A.A. (1954): The salmon problems associated with the proposed flood control project on the Okanagan River in British Columbia, Canada; unpublished report prepared by the technical staffs of the United States Fish and Wildlife Service, the Washington Department of Fisheries and the Canada Department of Fisheries, 109 p.

Hrasko, B. and McNeill, R. (2006): Costs of adaptation options; *in* Participatory Integrated Assessment of Water Management and Climate Change in the Okanagan Basin, British Columbia, (ed.) S. Cohen and T. Neale; final report for Project A846 submitted to Natural Resources Canada, Environment Canada and University of British Columbia, p. 43–56.

Hughes, R.G. (2004): Climate change and loss of saltmarshes: consequences for birds; Ibis, v. 146, supplement 1, p. 21–28.

Hutton, D. and Haque, C.E. (2004): Human vulnerability dislocation and resettlement-adaptation processes of river-bank erosion-induced displacees in Bangladesh; Disasters, v. 28, no. 1, p. 41–62.

Hyatt, K.D. and Alexander, C.A.D. (2005): The Okanagan Fish-Water Management OKFWM Tool: results of a 25 year retrospective analysis; unpublished report prepared for the Canadian Okanagan Basin Technical Working Group, Fisheries and Oceans Canada, and Douglas County Public Utility District No. 1, East Wenatchee, Washington, 24 p.

Hyatt, K.D. and Rankin, D.P. (1999): An evaluation of Okanagan sockeye salmon escapement objectives; Fisheries and Oceans Canada, Pacific Biological Station, Pacific Science Advisory Review Committee, Working Paper S99-18.

Hyatt, K.D. and Riddell, B.E. (2000): The importance of 'stock' conservation definitions of the concept of sustainable fisheries; *in* Sustainable Fisheries Management: Pacific Salmon, (ed.) E.E. Knutson, C.R. Steward, D. MacDonald, J.E. Williams and D.W. Reiser; CRC Press, Boca Raton, Florida, p. 51–62.

Hyatt, K.D., Stockwell, M.M. and Rankin, D.P. (2003): Impact and adaptation responses of Okanagan River sockeye salmon *Oncorhynchus nerka* to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications; Canadian Water Resources Journal, v. 28, p. 689–713.

Intergovernmental Panel on Climate Change (2001): Summary for policymakers; *in* Climate Change 2001: Impacts, Adaptation and Vulnerability (Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change), (ed.) J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White; Cambridge University Press, Cambridge, United Kingdom, 18 p., <http://www.ipcc.ch/pub/wg2SPMfinal.pdf>, [accessed May 18, 2007].

Intergovernmental Panel on Climate Change (2007): Summary for policymakers; *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), (ed.) S. Solomon; D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignot and H.L. Miller; Cambridge University Press, Cambridge, United Kingdom and New York, New York, 18 p., <http://www.ipcc.ch/SPM2feb07.pdf>, [accessed May 8, 2007].

Interis (2005): Climate change risk assessment for Fisheries and Oceans Canada; unpublished report prepared for Fisheries and Oceans Canada, Policy and Planning Branch, 50 p.

Irvine, J., Biagini, L. and Poon, M. (2005): An update on catch trends for Pacific salmon in British Columbia, Canada; Fisheries and Oceans Canada, Document NPAFC Doc-868, 14 p.

Jakob, M., McKendry, I. and Lee, R. (2003): Long-term changes in rainfall intensity in Vancouver, British Columbia; Canadian Water Resources Journal, v. 28, no. 4, p. 587–604.

Johnson, C. (2004): Dry weather starts flow of talk; Vancouver Sun, July 9, 2004.

Johnson, M. and Williamson, T.B. (2005): Climate change implications for stand yields and soil expectation values: a northern Saskatchewan case study; The Forestry Chronicle, v. 81, p. 683–690.

Kidd, S.E., Hagen, F., Tscharke, R.L., Huynh, M., Barlett, K.H., Fyfe, M., MacDougall, L., Boekhout, T., Kwon Chung, K.J. and Meyer, W. (2004): A rare genotype of Cryptococcus gattii caused the cryptococcosis outbreak on Vancouver Island (British Columbia, Canada); in Microbiology, Proceedings of The National Academy of Sciences of the United States of America, v. 101, no. 49, p. 17 258–17 263.

King, J.R., editor (2005): Report of the study group on fisheries and ecosystem response to recent regime shifts; North Pacific Marine Science Organization (PICES), Scientific Report 28, 168 p., <http://www.pices.int/publications/scientific_reports/Report28/Rep_28_default.aspx>, [accessed May 18, 2007].

King, J.R. and McFarlane, G.A. (2003): Marine fish life history strategies: applications to fishery management; Fisheries Management and Ecology, v. 10, p. 249–264.

Klein, R.J.T. and Nicholls, R.J. (1999): Assessment of coastal vulnerability to climate change; Ambio, v. 28, no. 2, p. 182–187.

Klinenberg, E. (2002): Heat wave: a social autopsy of disaster in Chicago; University of Chicago Press, Chicago, Illinois, 320 p.

Koch, J., Menounos, B., Clague, J.J. and Osborn, G.D. (2004): Environmental change in Garibaldi Provincial Park, southern Coast Mountains, British Columbia; Geoscience Canada, v. 31, p. 127–135.

Kondro, W. (2000): Software calculates pollution's cost to health; Lancet, v. 356, p. 144.

Krajina, V.J. (1965): Biogeoclimatic zones and biogeocoenoses of British Columbia; Ecology of Western North America, v. 1, p. 1–17.

Lambrakis, N. and Kallergis, G. (2001): Reaction of subsurface coastal aquifers to climate and land use changes in Greece: modelling of groundwater refreshening patterns under natural recharge conditions; Journal of Hydrology, v. 245, no. 1, p. 19–31.

Lanarc Consultants (2005): Stormwater source control design guidelines, 2005; Greater Vancouver Regional District, <http://www.gvrd.bc.ca/sewerage/stormwater_reports.htm>, [accessed May 18, 2007].

Langsdale, S., Beall, A., Carmichael, J., Cohen, S. and Forster, C. (2006): Description of the model; *in* Participatory Integrated Assessment of Water Management and Climate Change in the Okanagan Basin, British Columbia, (ed.) S. Cohen and T. Neale; Report submitted to the Climate Change Impacts and Adaptation Program, Natural Resources Canada, <http://adaptation.nrcan.gc.ca/projdb/pdf/a846_e.pdf>, [August 15, 2007].

Larocque, S.J. and Smith, D.J. (2003): Little Ice Age glacial activity in the Mt. Waddington area, British Columbia Coast Mountains, Canada; Canadian Journal of Earth Sciences, v. 40, p. 1413–1436.

Larocque, S.J. and Smith, D.J. (2004): Calibrated Rhizocarpon spp. growth curve for the Mount Waddington area, British Columbia Coast Mountains, Canada; Arctic, Antarctic, and Alpine Research, v. 36, p. 407–418.

Lee, K. (1993): Compass and Gyroscope: Integrating Science and Politics for the Environment; Island Press, Washington, DC, 255 p.

Leith, R.M. and Whitfield, P.H. (1998): Evidence of climate change effects on the hydrology of streams in south-central BC; Canadian Water Resources Journal, v. 23, p. 219–230.

Lemieux, C.J. and Scott, D. (2005): Climate change, biodiversity conservation, and protected areas planning in Canada; The Canadian Geographer, v. 49, no. 4, p. 384–397.

Levings, D.D. and Goda, T. (1991): Strategies for restoring and developing fish habitats in the Strait of Georgia–Puget Sound inland sea, northeast Pacific Ocean; Marine Pollution Bulletin, v. 23, p. 417–422.

Levy, D.A. (1992): Potential impacts of global warming on salmon production in the Fraser River watershed; Canadian Technical Report of Fisheries and Aquatic Sciences 1889.

Lewis, D.H., and Smith, D.J. (2004): Little Ice Age glacial activity in Strathcona Provincial Park, Vancouver Island, British Columbia, Canada; Canadian Journal of Earth Sciences, v. 41, p. 285–297.

Liebscher, H. (1987): Ground water action plan, conservation and protection, Pacific and Yukon region; Ground Water — Inland Waters/Lands, Vancouver, BC, unpublished report.

Lindgren E., Tälleklint L. and Polfeldt T. (2000): Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick (*Ixodes ricinus*); Environmental Health Perspectives, v. 108, no. 2, p. 119–123.

Liteanu, E. (2003): The role of aquifer heterogeneity in saltwater intrusion modelling, Saturna Island, British Columbia; M.Sc. thesis, Simon Fraser University, Vancouver, BC.

Logan, J.A. and Powell, J.A. (2001): Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae); American Entomologist, v. 47, p. 160–173, <http://www.usu.edu/beetle/documents/Logan_Powell01.pdf>, [accessed May 18, 2007].

Loukas, A., Vasiliades, L. and Dalezios, N.R. (2004): Climate change implications on flood response of a mountainous watershed; Water, Air, and Soil Pollution: Focus, v. 4, no. 4–5, p. 331–347.

Lowell, T.V. (2000): As climate changes, so do glaciers; Proceedings of the National Academy of Science, v. 97, no. 4, p. 1351–1354.

Luckman, B.H. (2000): The Little Ice Age in the Canadian Rockies; Geomorphology, v. 32, p. 357–384.

Luitzen, B., O'Callaghan, J., Hillen, R., Misdorp, R., Mieremet, B., Ries, K., Spradley, J.R. and Titus, J., editors (1992): Global climate change and the rising challenge of the sea; Intergovernmental Panel on Climate Change, Response Strategies Working Group, Coastal Zone Management Subgroup, Ministry of Transport, Public Works and Water Management, The Hague, Netherlands, 27 p.

MacDonald, S., Foreman, M., Farrell, T., Williams, I., Grout, J., Cass, A., Woodey, J., Enzenhoffer, H., Clarke, C., Houtman, R., Donaldson, E. and Barnes, D. (2000): The influence of extreme water temperatures on migrating Fraser River sockeye salmon (*Oncorhynchus nerka*) during the 1998 spawning season; Canadian Technical Report of Fisheries and Aquatic Sciences 2326.

Mantua, N.J. and Francis, R.C. (2004): Natural climate insurance for Pacific northwest salmon and salmon fisheries: finding our way through the entangled bank; *in* Fish in our Future? Perspectives on Fisheries Sustainability, (ed.) E.E. Knudsen and D. MacDonald; American Fisheries Society, Special Publication 43, p. 121–134.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. and Francis, R.C. (1997): A Pacific interdecadal climate oscillation with impacts on salmon production; Bulletin of the American Meteorological Society, v. 78, p. 1069–1079.

Marchak, P., Aycock, S. and Herbert, D. (1999): Falldown: forest policy in British Columbia; David Suzuki Foundation, Vancouver, BC.

Matthews, R. (2003): Using a social capital perspective to understand social and economic development in coastal British Columbia; Horizons: Policy Research Initiative, v. 63, p. 25–29.

Matthews, R. and Young, N. (2005): Development on the margin: development orthodoxy and the success of Lax Kw'alaams; British Columbia Journal of Aboriginal Economic Development, v. 4, no. 2, p. 100–108.

Matthews, R, and Young, N. (2007): Globalization and 'repositioning' in coastal British Columbia; *in* Reading Sociology - A Canadian Sociological Association Reader, (ed.) L. Tepperman and H. Dickinson; Oxford University Press.

Mazzotti, S., Lambert, T., Van der Kooij, M. and Mainville, A. (2006): Coastal subsidence and relative sea-level rise in the Fraser River delta, Greater Vancouver, BC, from a combined CTM-InSAR, GPS, leveling, and tide gauge analysis; American Geophysical Union, Fall Meeting, December 11–16, 2006, San Francisco, California, p. 11–15.

McBean, G. and Henstra, D. (2003): Climate change, natural hazards and cities; Institute for Catastrophic Loss Reduction, Research Paper Series, No. 31, 11 p., <http://www.dmrg.org/resources/McBean.Henstra-Climate%20change,%20natural%20hazards%20and%20cities.pdf>, [accessed May 18, 2007].

McFarlane, G.A. and Beamish, R.J. (1998): Sardines return to British Columbia waters; *in* Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and its Marginal Seas; North Pacific Marine Science Organization (PICES), Scientific Report 10, 5 p. <http://www.pices.int/publications/scientific_reports/Report10/mcfarlane.pdf>, [accessed May 18, 2007].

McGeehin, M.A. and Mirabelli, M. (2001): The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States; Environmental Health Perspectives, v. 9, supplement 2, p. 185–189.

McKenzie, D., Gedalof, Z., Peterson, D.L. and Mote, P. (2004): Climatic change, wildfire, and conservation; Conservation Biology, v. 18, p. 890–902.

McKinnell, S.M., Wood, C.C., Rutherford, D.T., Hyatt, K.D. and Welch, D.W. (2001): The demise of Owikeno Lake sockeye salmon; North American Journal of Fisheries Management, v. 21, p. 774–791.

McMichael, A.J., Campbell-Lendrum, D.H., Corvalán, C.F., Ebi, K.L., Githeko, A., Scheraga, J.D. and Woodward, A. (2003): Climate change and human health — risks and responses; World Health Organization, Geneva, Switzerland, 322 p.

McPhaden, M.J. and Zhang, D. (2002): Slowdown of the meridional overturning circulation in the upper Pacific Ocean; Nature, v. 415, p. 603–608.

McRae, D. (1997): Regional population trends in BC; presentation to The 27th Annual Outlook Conference, Association of Professional Economists, November 19, 1997 by BC Ministry of Finance and Corporate Relations, BC Stats, 19 p., <http://www.bcstats.gov.bc.ca/data/pop/pop/apebc97.pdf>, [accessed May 18, 2007].

Menounos, B., Koch, J., Osborn, G., Clague. J.J. and Mazzucchi, D. (2004): Early Holocene glacier advance, southern Coast Mountains, British Columbia, Canada; Quaternary Science Reviews, v. 23, p. 1543–1550.

Merritt, W., Alila, Y., Barton, M., Taylor, B., Cohen, S. and Neilsen, D. (2006): Hydrologic response to scenarios of climate change in subwatersheds of the Okanagan Basin, British Columbia; Journal of Hydrology, v. 326, p. 79–108.

Miles, E.L., Snover, A.K., Hamlet, A.F., Callahan, B. and Fluharty, D. (2000): Pacific Northwest regional assessment: the impacts of climate variability and climate change on the water resources of the Columbia River basin; Journal of the American Water Resources Association, v. 36, no. 2, p. 399–420.

Miles, M. and Associates (2003): BC's climate related observation networks: an adequacy review; BC Ministry of the Environment, Victoria, BC, 107 p. <ftp://ftp.env.gov.bc.ca/pub/outgoing/Climate%20Change/>, [accessed May 25, 2007].

Mills, J.N., Yates T.L., Ksiazek, T.G., Peter, C.J. and Childs, J.E. (1999): Long term studies of Hantavirus reservoir populations in the southwestern United States: rationale, potential, and methods; Emerging Infectious Diseases, v. 5, p. 95–101.

Milly, P.C.D., Wetherald, R.T., Dunne, K.A. and Delworth, T.L. (2002): Increasing risk of great floods in a changing climate; Nature, v. 415, p. 514–517.

Mitchell, W.R., Green, R.N., Hope, G.D. and Klinka, K. (1989): Methods for biogeoclimatic ecosystem mapping; BC Ministry of Forestry, Resources Report 89002-KL, 33 p., <http://www.for.gov.bc.ca/hfd/pubs/docs/rr/r89002-kl.pdf>, [accessed August 6, 2007].

Moore, R.D. (2006): Stream temperature patterns in British Columbia, Canada, based on routine spot measurements; Canadian Water Resources Journal, v. 31, p. 1–16.

Moore, R.D., Spittlehouse, D.L. and Story, A. (2005): Riparian microclimate and stream temperature response to forest harvesting — a review; Journal of the American Water Resources Association, v. 41, p. 813–834.

Moorhouse, J. (2003): Water crisis; Penticton Herald, July 31, 2003.

Morrison, J., Quick, M.C. and Foreman, M.G.G. (2002): Climate change in the Fraser River watershed: flow and temperature projections; Journal of Hydrology, v. 263, no. 1, p. 230–244.

Morshed, M.G. (2003): West Nile virus in North America: coast to coast?; Canadian Medical Proficiency Testing Connections, v. 64, p. 2–3.

Morton, A., Routledge, R., Peet, C. and Ladwig, A. (2005): Sea lice Lepeophtheirus salmonis infection rates on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon in the nearshore marine environment of British Columbia, Canada; Canadian Journal of Fisheries and Aquatic Science, v. 61, p. 147–157.

Mote, P.W. (2003a): Twentieth-century fluctuation and trends in temperature, precipitation, and mountain snowpack in the Georgia Basin–Puget Sound region; Canadian Water Resources Journal, v. 28, no. 4, p. 567–585.

Mote, P.W. (2003b): Trends in snow water equivalent in the Pacific Northwest and their climatic causes; Geophysical Research Letters, v. 30, no. 12, p. 1601–1604.

Mote, P.W. (2003c): Trends in temperature and precipitation in the Pacific Northwest during the twentieth century; Northwest Science, v. 77, no. 44, p. 271–282.

Mote, P.W. and Hamlet, A.F. (2001): Anthropogenic climate change and snow in the Pacific Northwest; *in* Proceedings of the 69th Annual Meeting of the Western Snow Conference, April 16–19, 2001, Sun Valley, Idaho, p. 51–52.

Mote, P.W., with Canning, D., Fluharty, D., Francis, R., Franklin, J, Hamlet, A., Hershman, M., Holmberg, M., Ideker, K., Keeton, W., Lettenmaier, D., Leung, R., Mantua, N., Miles, E., Noble, B., Parandvash, H., Peterson, D.W., Snover, A. and Willard, S. (1999): Impacts of climate variability and change: Pacific Northwest; Report of the Pacific Northwest Regional Assessment Group for the United States Global Change Research Program, Joint Institute for the Study of Atmosphere and Ocean/SMA Climate Impacts Group, University of Washington, Seattle, Washington.

Mote, P.W., Hamlet, A.F., Clark, M.P. and Lettenmaier, D.P. (2005): Declining snowpack in western North America; Bulletin of the American Meteorological Society, v. 86, p. 39–49.

Mote, P.W., Parson, E.A., Hamlet, A.F., Ideker, K.N., Keeton, W.S., Lettenmaier, D.P., Mantua, N.J., Miles, E.L., Peterson, D.W., Peterson, D.L., Slaughter, R. and Snover, A.K. (2003): Preparing for climate change: the water, salmon and forests of the Pacific Northwest; Climatic Change, v. 61, no. 1–2, p. 45–88.

Muckle, R. (1998): The First Nations of British Columbia: An Anthropological Survey; University of British Columbia Press, Vancouver, BC, 146 p.

Mudie, P.J., Rochon, A. and Levac, E. (2002): Palynological records of red tide–producing species in Canada: past trends and implications for the future; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 180, p. 159–186.

Mullens, A. (1996): I think we have a problem in Victoria: MDs respond quickly to toxoplasmosis outbreak in BC; Canadian Medical Association Journal, v. 154, no. 11, p. 1721–1724.

Natural Resources Canada (2006): Energy Star®, EnerGuide and R-2000 website; Natural Resources Canada, Office of Energy Efficiency, <http://oee.nrcan.gc.ca/residential/energystar-energuide-r2000.cfm?attr=4>, [accessed May 18, 2007].

Natural Resources Canada (2007):The Mountain Pine Beetle (MPB) Program, <http://mpb.cfs.nrcan.gc.ca/map_e.html>, [accessed October 31, 2007].

Naylor, R., Eagle, J. and Smith, W.L. (2003): Salmon aquaculture in the Pacific Northwest: a global industry; Environment, v. 45, no. 8, p. 18–39.

Neale, T., Carmichael, J. and Cohen, S. (2006): Urban water futures: exploring development, management and climate change impacts on urban water demand; *in* Participatory Integrated Assessment of Water Management and Climate Change in the Okanagan Basin, British Columbia, (ed.) S. Cohen and T. Neale; Environment Canada and University of British Columbia, Vancouver, BC, p. 7–35.

Neilsen, D., Koch, W., Merritt, W., Frank, G., Smith, S., Alila, Y., Carmichael, J., Neale, T. and Welbourn, R. (2004a): Risk assessment and vulnerability — case studies of water supply and demand; *in* Expanding the Dialogue on Climate Change and Water Management in the Okanagan Basin, British Columbia, (ed.) S. Cohen, D. Neilsen and R. Welbourn; Government of Canada, p. 115–135, <http://www.ires.ubc.ca/downloads/publications/layout_Okanagan_final.pdf>, [accessed July 25, 2007].

Neilsen, D., Koch, W., Smith, S. and Frank, G. (2004b): Crop water demand scenarios for the Okanagan Basin; *in* Expanding the Dialogue on Climate Change and Water Management in the Okanagan Basin, British Columbia, (ed.) S. Cohen, D. Neilsen and R. Welbourn; Government of Canada p. 89–112, <http://www.ires.ubc.ca/downloads/publications/layout_Okanagan_final.pdf>, [accessed July 25, 2007].

Neilsen, D., Smith, C.A.S., Koch, W., Frank, G., Hall, J. and Parchomchuk, P. (2001): Impact of climate change on irrigated agriculture in the Okanagan Valley, British Columbia; report to the Climate Change Impacts and Adaptation Program, Natural Resources Canada, Ottawa, Ontario, 29 p.

Neilsen, D., Smith, S., Frank, G., Koch, W., Alila, Y., Merritt, W., Taylor, B., Barton, M., Hall, J. and Cohen, S. (2006): Potential impacts of climate change on water availability for crops in the Okanagan Basin, British Columbia; Canadian Journal of Soil Science, v. 86, p. 921–936.

Neilsen G.H., Hogue, E.J., Forge, T. and Neilsen, D. (2003): Surface application of mulches and biosolids affect orchard soil properties after 7 years; Canadian Journal of Soil Science, v. 83, p. 131–137

Noakes, D.J., Beamish, R.J. and Gregory, R. (2002): British Columbia's commercial salmon industry; North Pacific Anadromous Fish Commission, Document 642, 13 p.

Northcote, T.G. (1992): Prediction and assessment of potential effects of global environmental change on freshwater sport fish habitat in British Columbia; GeoJournal, v. 28, p. 39–49.

Northcote, T.G. (1996): Effects of human population growth on the Fraser and Okanagan River systems, Canada: a comparative inquiry; GeoJournal, v. 40, p. 127–133.

O'Brien, K.L. and Leichenko, R.M. (2000): Double exposure: assessing the impacts of climate change within the context of economic globalization; Global Environmental Change, v. 10, no. 3, p. 221–232.

Ohlson, D.W., McKinnon, G.A. and Hirsch, K.G. (2005): A structured decision-making approach to climate change adaptation in the forest sector; The Forestry Chronicle, v. 81, no. 1, p. 672–677.

Ommer, R.E. (2006): The impact of social and environmental restructuring on environmental and human health in Canada; Coasts Under Stress, Victoria, BC, 7 p., <http://www.coastsunderstress.ca/pubs/CUSResultsSummary2006.pdf>, [accessed May 18, 2007].

Ommer, R.E. (2007): Coasts Under Stress: Restructuring and Social-Ecological Health; McGill-Queen's University Press, Montréal, Quebec, 624 p.

O'Neil, J.D., Elias, B. and Yassi, A. (1997): Poisoned food: cultural resistance to the contaminations discourse in Nunavik; Arctic Anthropology, v. 34, p. 29–40.

Overpeck, J.T., Bartlein, P.J. and Webb, T.I. (1991): Potential magnitude of future vegetation change in eastern North America: comparisons with the past; Science, v. 254, p. 692–695.

Pacific Fisheries Resource Conservation Council (2006): Implementing the habitat and ecosystem components of DFO's wild salmon policy; Pacific Fisheries Resource Conservation Council, Vancouver, BC, 34 p., <http://www.fish.bc.ca/files/R-42%20Advisory-DFOWildSalmonPolicy_2006_0_Complete.pdf>, [accessed May 18, 2007].

Page, J., Enns, S., Malinick, T. and Matthews, R. (2007): Should I stay or should I go?: investigating resilience in BC's coastal communities; *in* Sociology in Canada — A Canadian Sociological Association Reader, (ed.) L. Tepperman and H. Dickinson; Oxford University Press, Toronto, Ontario, p. 260–263.

Palmer, T.N. and Rälsänen, J. (2002): Quantifying the risk of exteme seasonal precipitation events in a changing climate; Nature, v. 415, p. 512–514.

Parker, W.C., Colombo, S.J., Cherry, M.L., Flannigan, M.D., Greifenhagen, S., McAlpine, R.S., Papadopol, C. and Scarr, T. (2000): Third millennium forestry: what climate change might mean to forests and forest management in Ontario; The Forestry Chronicle, v. 76, p. 445–463.

Parkinson, A.J. and Butler, J.C. (2005): Potential impacts of climate change on infectious diseases in the Arctic; International Circumpolar Health, v. 64, no. 5, p. 478–486.

Payne, J.T., Wood, A.W., Hamlet, A.F., Palmer, R.N. and Lettenmaier, D.P. (2004): Mitigating the effects of climate change on the water resources of the Columbia River basin; Climatic Change, v. 62, no. 3, p. 233–256.

Pearse, P.H. and Larkin, P.A. (1992): Managing salmon in the Fraser: executive summary; report to the Minister of Fisheries and Oceans Canada on the Fraser River Salmon Investigation, November 1992, p. 3.

Pearse, P.H. (1982): Turning the tide: a new policy for Canada's Pacific fisheries; final report of the Commission on Pacific Fisheries Policy, Canada Ministry of Supply and Services.

Pederson, L. (2004): Prince George timber supply area: rationale for allowable annual cut AAC determination; BC Ministry of Forests, Forest Analysis and Inventory Branch, Victoria, BC, <http://www.for.gov.bc.ca/hts/tsr1/ration/tsa/tsa24/httoc.htm>, [accessed May 20, 2007].

Perez-Garcia, J., Joyce, L.A., McGuire, A.D. and Xiao, X. (2002): Impacts of climate change on the global forest sector; Climatic Change, v. 54, p. 439–461.

Pezzey, J. (1989): Economic analysis of sustainable growth and sustainable development; World Bank, Environment Department, Working Paper 15, Washington, DC.

Pojar, J. and Meidinger, D.V. (1991): Ecosystems of British Columbia; BC Ministry of Forests, Forest Science Program, Special Report Series 6, 330 p., <http://www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.htm>, [accessed May 18, 2007].

Public Safety and Emergency Preparedness Canada (2006a): British Columbia Emergency Response Management System (BCERMS); Public Safety and Emergency Preparedness Canada, <http://www.pep.gov.bc.ca/bcerms/bcerms.html>, [accessed May 18, 2007].

Public Safety and Emergency Preparedness Canada (2006b): Canadian Disaster Database; Public Safety and Emergency Preparedness Canada, <http://www.psepc-sppcc.gc.ca/res/em/cdd/index-en.asp>, [accessed May 18, 2007].

Pulwarty, R.S. and Redmond, K.T. (1997): Climate and salmon restoration in the Columbia River basin: the role and usability of seasonal forecasts; Bulletin of the American Meteorological Society, v. 78, p. 381–397.

Quilty, E.J., Hudson, P. and Farahmand, T. (2004): Living on the edge: climate change and salmon in Lang Creek, British Columbia; unpublished report prepared by Aquatic Informatics Inc. for BC Ministry of Water, Land and Air Protection, 68 p., <wlapwww.gov.bc.ca/sry/p2/eq/special_studies/lang_creek/lang_creek.pdf>, [accessed May 18, 2007].

Raphael, D. (2001): From increasing poverty to social disintegration: how economic inequality affects the health of individuals and communities; *in* Unhealthy Times, (ed.) P. Armstrong, H. Armstrong and D. Coburn; Oxford University Press, Oxford, United Kingdom, p. 223–246.

Raunet, D. (1984): Without Surrender, Without Consent: A History of the Nishga Land Claims; Douglas and Mclntyre, Vancouver, BC, 244 p.

Raven, J., Caldeira, K., Elderfield, H., Liss, P. and Turley, C. (2005): Ocean acidification due to increasing atmospheric carbon dioxide; The Royal Society, London, United Kingdom, Policy Document 12/05, 60 p.

Reed, M.G. and Gill, A.M. (1997): Tourism, recreational and amenity values in land allocation: an analysis of institutional arrangements in the postproductivist era; Environment and Planning A, v. 29, no.11, p. 2019–2040.

Rehfeldt, G.E., Wykoff, W.R. and Cheng, C.Y. (2001): Physiologic plasticity, evolution and impacts of a changing climate on Pinus contorta; Climatic Change. v. 50, p. 355–376.

Rehfeldt, G.E., Ying, C.C., Spittlehouse, D.L. and Hamilton, D.A. (1999): Genetic responses to climate for Pinus contorta: niche breadth, climate change, and reforestation; Ecological Monographs, v. 69, p. 375–407.

Riddell, B. (2004): Pacific salmon resources in central and north coast British Columbia; Pacific Fisheries Resource Conservation Council, Vancouver, BC, <http://www.fish.bc.ca/files/SalmonResources-North_2004_0_Complete.pdf>, [accessed May 18, 2007].

Rivera, A., Allen, D.M. and Maathuis, H. (2004): Climate variability and change — groundwater resources; in Threats to Water Availability in Canada; Environment Canada, National Water Research Institute, p. 77–83.

Robinson, C.L.K. and Ware, D.M. (1994): Simulated and observed response of the southwest Vancouver Island pelagic ecosystem to oceanic conditions in the 1990s; Canadian Journal of Fisheries and Aquatic Sciences, v. 56, p. 2433–2443.

Rosenau, M.L. and Angelo, M. (2003): Conflicts between people and fish for water: two British Columbia salmon and steelhead rearing streams in need of flows; unpublished report to the Pacific Fisheries Resource Conservation Council, Vancouver, BC, <http://www.fish.bc.ca/files/ConflictsPeopleFish_2003_0_Complete.pdf>, [accessed May 18, 2007].

Rosenberg, S.M., Walker, I.R., Mathewes, R.W. and Hallett, D.J. (2004): Midge-inferred Holocene climate history of two subalpine lakes in southern British Columbia; The Holocene, v. 14, p. 258–271.

Royal BC Museum (2005a): Climate change map series; Royal BC Museum, <http://www.pacificclimate.org/impacts/rbcmuseum/>, [accessed May 20, 2007].

Royal BC Museum (2005b): Cooling and heating energy requirements by 2080 with various climate change scenarios; Royal BC Museum, <http://www.pacificclimate.org/impacts/rbcmuseum/>, [accessed May 20, 2007].

Ryder, J.M. and Thomson, B. (1986): Neoglaciation in the southern Coast Mountains of British Columbia: chronology prior to the Neoglacial maximum; Canadian Journal of Earth Sciences, v. 23, p. 273–287.

Safranyik, L. and Carroll, A.L. (2006): The biology and epidemiology of the mountain pine beetle in lodgepole pine forests; *in* The Mountain Pine Beetle: A Synthesis of its Biology, Management and Impacts on Lodgepole Pine, (ed.) L. Safranyik and B. Wilson; Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, p. 3–36.

Safranyik, L., Shrimpton, D.M. and Whitney, H.S. (1975): An interpretation of the interaction between lodgepole pine, the MPB and its associated blue stain fungi in western Canada; *in* Management of Lodgepole Pine Ecosystems, (ed.) D.M. Baumgartner; Washington State University, Cooperative Extension Services, Pullman, Washington, p. 406–428.

Sandford, B. (2006): Climate change in the Columbia basin; Columbia Basin Trust, Revelstoke, BC, 20 p.

Schumacher, R.S. and Johnson, R.H. (2005): Organization and environmental properties of extreme-rain-producing mesoscale convective systems; Monthly Weather Review, v. 133, p. 961–976.

Schweigert, F.J. (1993): Effects of fasting and lactation on blood chemistry and urine composition in the grey seal Halichoerus grypus; Comparative Biochemistry and Physiology, v. 105A, p. 353–357

Scibek, J. and Allen, D.M. (2006): Comparing the responses of two high permeability, unconfined aquifers to predicted climate change; Global and Planetary Change, v. 50, p. 50–62.

Scott, D. (2003a): Climate change and Canada's national park system: scenarios and impacts; Parks Canada, Ecosystem Science and Review Reports, no. 19, CD-ROM.

Scott, D. (2003b): Climate change and tourism in the mountain regions of North America; presentation at First International Conference on Climate Change and Tourism, Djerba, Tunisia. April 9–11, 2003, 9 p. <http://www.world-tourism.org/sustainable/climate/pres/daniel-scott.pdf>, [accessed May 25, 2007].

Scott, D. (2006a): Global environmental change and mountain tourism; *in* Tourism and Global Environmental Change, (ed.) S. Gössling and C.M. Hall; Routledge, London, United Kingdom, p. 54–75.

Scott, D. (2006b): US ski industry adaptation to climate change: hard, soft and policy strategies; *in* Tourism and Global Environmental Change, (ed.) S. Gössling and C.M. Hall; Routledge, London, United Kingdom, p. 262–285.

Scott, D. and Lemieux, C. (2005): Climate change and protected area policy and planning in Canada; The Forestry Chronicle, v. 81, p. 696–703.

Scott, D. and Suffling, R., editors (2000): Climate change and Canada's national park system; Environment Canada and Parks Canada, 218 p., <http://www.fes.uwaterloo.ca/geography/faculty/danielscott/PDFFiles/CC&Canada%20National%20Parks-Report%202000.pdf>, [accessed May 18, 2007].

Scott, D., McBoyle, G. and Mills, B. (2003): Climate change and the skiing industry in southern Ontario, Canada: exploring the importance of snowmaking as a technical adaptation; Climate Research, v. 23, p. 171–181.

Scott, D., Wall, G. and McBoyle, G. (2005): Climate change and tourism and recreation in North America: exploring regional risks and opportunities; *in* Tourism, Recreation and Climate Change, (ed.) C.M. Hall and J. Higham; Channel View, Clevedon, United Kingdom, p. 115–129.

Seely, B., Nelson, J., Wells, R., Peter, B., Meitner, M., Anderson, A., Harshaw, H., Sheppard, S., Bunnell, F.L., Kimmins, H. and Harrison, D. (2004): The application of a hierarchical, decision-support system to evaluate multi-objective forest management strategies: a case study in northeastern British Columbia; Canada Forest Ecology and Management, v. 199, p. 283–305.

Shafer, S.L., Bartlein, P.J. and Thompson, R.S. (2001): Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios; Ecosystems, v. 4, p. 200–215.

Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M.H. and Solomon, S. (1998): Sensitivity of the coasts of Canada to sea-level rise; Geological Survey of Canada, Bulletin 505, 79 p.

Shepard, M.P. and Argue, A.W. (2005): The 1985 Pacific Salmon Treaty: sharing the burdens and benefits; University of British Columbia Press, Vancouver, BC, 304 p.

Shepherd, P., Tansey, J. and Dowlatabadi, H. (2006): Context matters: what shapes adaptation to water stress in the Okanagan?; Climatic Change, v. 78, no. 1, p. 31–62.

Sieben, B.G., Spittlehouse, D.L., Benton, R.A. and McLean, J.A. (1997): A first approximation of the effect of climate warming on the white pine weevil hazard in the Mackenzie River drainage basin; *in* Mackenzie Basin Impact Study Final Report, (ed.) S.J. Cohen; Environment Canada, p. 166–177.

Slaney, T.L., Hyatt, K.D., Northcote, T.G. and Fielden, R.J. (1996): Status of anadromous salmon and trout in British Columbia and Yukon; Fisheries, v. 21, p. 20–35.

Smit, B., Pilifosova, O., Burton I., Challenger B., Huq S., Klein R.J.T. and Yohe, G. (2001): Adaptation to climate change in the context of sustainable development and equity; *in* Climate Change 2001: Impacts, Adaptation, and Vulnerability (Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change), (ed.) J.J. McCarthy, O.F. Canzianni, N.A. Leary, D.J. Dokken and K.S. White; Cambridge University Press, Cambridge, United Kingdom, p. 877–912.

Smith, B.E. (1998): Planning for agriculture; BC Provincial Agricultural Land Commission, <http://www.landcommission.gov.bc.ca/publications/planning/pfa_main.htm>, [accessed May 18, 2007].

Smith, C.L., Gilden, J. and Steel, B. (1998): Sailing the shoals of adaptive management: the case of salmon in the Pacific Northwest; Environmental Management, v. 225, p. 671–681.

Smoyer-Tomic, K.E., Kuhn, R and Hudson, A. (2003): Heat wave hazards: an overview of heat waves impacts in Canada; Natural Hazards, v. 28, p. 463–485.

Sohngen, B. and Sedjo, R. (2005): Impacts of climate change on forest product markets: implications for North American producers; The Forestry Chronicle, v. 81, p. 669–674.

Solow, R. (1991): Sustainability: an economist perspective; *in* Economics of the Environment: Selected Readings, (ed.) R. Dorfman and S. Dorfman; W.W. Norton and Company, New York, New York, p. 179–187.

Spittlehouse, D.L. (2003): Water availability, climate change and the growth of Douglas-fir in the Georgia Basin; Journal of Canadian Water Resources, v. 28, p. 673–688.

Spittlehouse, D.L. (2005): Integrating climate change adaptation into forest management; The Forestry Chronicle, v. 81, p. 691–695.

Spittlehouse, D.L. and Stewart, R.B. (2003): Adapting to climate change in forest management; Journal of Ecosystems and Management, v. 41, p. 7–17.

Stahl, K., Moore, R.D. and McKendry, I.G. (2006): The role of synoptic-scale circulation in the linkage between large-scale ocean-atmosphere indices and winter surface climate in British Columbia, Canada; International Journal of Climatology, v. 264, p. 541–560.

Stanbury, W.T. (2000): Environmental groups and the international conflict over the forests of British Columbia, 1990 to 2000: SFU-UBC Centre for the Study of Government and Business, Vancouver, BC, 412 p.

Statistics Canada (2001): Census of population: population and dwelling counts; Statistics Canada, <http://www12.statcan.ca/english/census01/Products/Standard/popdwell/tables.cfm>, [accessed May 18, 2007].

Statistics Canada (2005): CANSIM: projected population by age group according to three projection scenarios for 2006, 2011, 2016, 2021, 2026 and 2031, at July 1; Statistics Canada, <http://www40.statcan.ca/l01/cst01/demo08a.htm>, [accessed May 18, 2007].

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K. and Lima, M. (2002): Ecological effects of climate fluctuations; Science, v. 297, p. 1292–1296.

Stephen, C., Johnson, M. and Bell, A. (1994): First reported case of Hantavirus Pulmonary Syndrome in Canada; Canada Communicable Disease Report, v. 20, p. 121–125.

Stewart, I.T., Cayan, D.R. and Dettinger, M.D. (2004): Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario; Climatic Change, v. 62, p. 217–232.

Stewart, R.B., Wheaton, E. and Spittlehouse, D.L. (1998): Climate change: implications for the boreal forest; *in* Emerging Air Issues for the 21st Century: The Need for Multidisciplinary Management, (ed.) A.H. Legge and L.L. Jones; Air and Waste Management Association, Pittsburg, Pennsylvania, p. 86–101.

Storlazzi, C.D., Willis, C.M. and Griggs, G.B. (2000): Comparative impacts of the 1982–3 and 1997–8 El Niño winters on the central California coast; Journal of Coastal Research, v. 16, p. 1022-1036.

Subbotina, M.M., Thomson, R.E. and Rabinovich, A.B. (2001): Spectral characteristics of sea level variability along the west coast of North America during the 1982–83 and 1997–98 El Niño events; Progress in Oceanography, v. 49, p. 353–372.

Suffling, R. and Scott, D. (2002): Assessment of climate change effects on Canada's national park system; Environmental Monitoring and Assessment, v. 74, p. 117–139.

Summit Environmental (2004): Trepanier Landscape Unit Water Management Plan; Regional District of Central Okanagan, Kelowna, BC, 256 p., <http://www.regionaldistrict.com/docs/planning/Final_Report_Text.pdf>, [accessed May 20, 2007].

Sydneysmith R., Matthews, R, Satterfield, T. and Young, N. (2007) The co-management of climate change in coastal communities of British Columbia: social capital, trust and capacity; Canadian Climate Impacts and Adaptation Program, Natural Resources Canada, Project A1115 final report, 148 p.

Tansey, J. and Langsdale, S. (2004): Exploring anticipatory adaptation in the Okanagan, BC; *in* Expanding the Dialogue on Climate Change and Water Management in the Okanagan Basin, British Columbia, (ed.) S.J. Cohen, D. Neilsen and R. Welbourn; Environment Canada, p. 165–174.

Taylor, F.J.R. (1993): Current problems with harmful phyto-plankton blooms in British Columbia water; *in* Toxic Phytoplankton Blooms in the Sea, (ed.) T.J. Smayda and Y. Shimizu; Elsevier Scientific Publications, Amsterdam, The Netherlands, p. 699–703.

Taylor, S.W. and Carroll, A.L. (2004): Disturbance, forest age dynamics and mountain pine beetle outbreaks in BC: a historical perspective; *in* Challenges and Solutions: Proceedings of the Mountain Pine Beetle Symposium, (ed.) T.L. Shore, J.E. Brooks and J.E. Stone; Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, p. 41–51.

Taylor, S.W., Carroll, A.L., Alfaro, R.I. and Safranyik, L. (2006): Forest, climate and mountain pine beetle outbreak dynamics in western Canada; *in* The Mountain Pine Beetle: A Synthesis of Biology, Management, and Impacts on Lodgepole Pine, (ed.) L. Safranyik and B. Willson; Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, p. 67–94.

Tennant, P. (1990): Aboriginal Peoples and Politics: The Indian Land Question in British Columbia, 1849–1989; University of British Columbia Press, Vancouver, BC, 305 p.

Timmermann, A. (1999): Detecting the nonstationary response of ENSO to greenhouse warming; Journal of Atmospheric Sciences, v. 56, no. 14, p. 2313–2325.

Tobin, G. (1999): Sustainability and community resilience: the holy grail of hazards planning?; Environmental Hazards, v. 1, p. 13–25.

Tourism BC (2005a): British Columbia tourism top ten facts; Tourism BC, <http://www.tourismbc.com/template.asp?id=10>, [accessed May 18, 2007].

Tourism BC (2005b): Characteristics of the commercial nature-based tourism industry in British Columbia; Tourism BC, Research Services, 101 p., <http://www.tourismbc.com/PDF/Characteristics%20of%20Commercial%20Nature-Based%20Tourism.pdf>, [accessed May 18, 2007].

Transport Canada (2005): On the move — the facts, autumn 2005; Transport Canada, Pacific Region, Transport Trends, <http://www.tc.gc.ca/pacific/publication/tt_autumn05.htm>, [accessed May 18, 2007].

Trenberth, K.E. and Hurrell, J.W. (1994): Decadal atmosphere-ocean variations in the Pacific; Climate Dynamics, v. 96, p. 303–319.

Troendle, C.A. and Nankervis, J.E. (2000): Estimating additional water yield from changes in management of national forests in the North Platte basin; Bureau of Reclamation, Platte River Office, Lakewood, Colorado, 51 p.

University of British Columbia (no date): ClimateBC: a program to generate climate normal data for genecology and climate change studies in western Canada; University of British Columbia, Faculty of Forestry, Centre for Forest Gene Conservation, <http://genetics.forestry.ubc.ca/cfgc/climate-models.html>, [accessed May 18, 2007].

Uysal, M. (1998): The determinants of tourist demand: a theoretical perspective; *in* The Economic Geography of the Tourist Industry, (ed.) D. Ioannides and K.G. Debbage; Routledge, London, United Kingdom, p. 79–97.

Valentine, K.W.G., Sprout, P.N., Baker, T.E. and Lavkulich, L.M. (1978): The soil landscapes of British Columbia; BC Ministry of Environment, Resource Analysis Branch, 19 p.

Vancouver Economic Development (2006): Key sectors; Vancouver Economic Development, <http://www.vancouvereconomic.com/key_sectors/default.htm>, [accessed May 18, 2007].

Van Eeden, S.F., Tan, W., Suwa, T., Mukae, H., Terashima, T., Fujii, T., Qui, D., Vincent, R. and Hogg, J. (2001): Cytokines involved in the systemic inflammatory response induced by exposure to particulate matter air pollutants (PM10); American Journal of Respiratory and Critical Care Medicine, v. 164, no. 5, p. 826–830.

Vedal, S. (1993): Health effects of wood smoke; unpublished report prepared for the Provincial Health Officer of British Columbia, BC Ministry of Health, Victoria, BC.

Vermeer, K., Butler, R.W. and Morgan, K.H. (1994): Comparison of seasonal shorebird and waterbird densities within Fraser River delta intertidal regions; *in* The Abundance and Distribution of Estuarine Birds in the Strait of Georgia, British Columbia, (ed.) R.W. Butler and R.W. Campbell; Canadian Wildlife Service, Occasional Paper 65, p. 6–17.

Vincent, L.A. and Mekis, É. (2006): Changes in daily and extreme temperature and precipitation indices for Canada over the twentieth century; Atmosphere-Ocean, v. 44, no. 2, p. 177–193.

Volkman, J.M. (1997): A river in common: the Columbia River, the salmon ecosystem, and water policy; unpublished report prepared for the Western Water Policy Review Advisory Commission, 207 p., <https://repository.unm.edu/dspace/bitstream/1928/2809/1/COLUMBIA.pdf>, [accessed May 18, 2007].

Volney, W.J.A. and Hirsch, K.G. (2005): Disturbing forest disturbances; The Forestry Chronicle, v. 81, p. 662–668.

Walker, I.J. and Barrie, J.V. (2006): Geomorphology and sea-level rise on one of Canada's most 'sensitive' coasts: northeast Graham Island, British Columbia; *in* Proceedings of the 8th International Coastal Symposium; Journal of Coastal Research, Special Issue 39, 7 p.

Walker, I.R. and Pellatt, M. (2003): Climate change in coastal British Columbia — a paleoenvironmental perspective; Canadian Water Resources Journal, v. 28, p. 531–566.

Walker, I.J., Barrie, J.V., Dolan, A.H., Gedalof, Z., Manson, G., Smith, D. and Wolfe, S. (2007): Coastal vulnerability to climate change and sea level rise, Northeast Graham Island, Haida Gwaii (Queen Charlotte Islands), British Columbia: final technical report; report submitted to Climate Change Impacts and Adaptation Program, Natural Resources Canada, 249 p.

Wallis, P.M., Erlandsen, S.L., Isaac-Renton, J.L., Olson, M.E., Robertson, W.J. and van Keulen, H. (1996): Prevalence of Giardia cysts and Cryptosporidium oocysts and characterization of Giardia spp. isolated from drinking water in Canada; Applied Environmental Microbiology, v. 62, p. 2789–2797.

Wang, T.L., Hamann, A., Spittlehouse, D.L. and Aitken, S.N. (2006): Development of scale-free climate data for western Canada for use in resource management; International Journal of Climatology, v. 26, no. 3, p. 383–397.

Ware, D.M. and McFarlane, G.A. (1989): Fisheries production domains in the northeast Pacific Ocean; *in* Effects of Ocean Variability on Recruitment and an Evaluation of Parameters Used in Stock Assessment Models, (ed.) R.J. Beamish and G.A. McFarlane; Canadian Special Publication of Fisheries and Aquatic Sciences 108, p. 359–379.

Ware, D.M. and McFarlane, G.A. (1995): Climate induced changes in hake abundance and pelagic community interactions in the Vancouver Island upwelling system; *in* Climate Change and Northern Fish Populations, (ed.) R.J. Beamish; Canadian Special Publication of Fisheries and Aquatic Sciences 121, p. 509–521.

Ware, D.M. and Thomson, R.E. (2000): Interannual to multi-decadal timescale climate variations in the northeast Pacific; Journal of Climate, v. 13, p. 3209–3220.

Ware, D.M. and Thomson, R.E. (2005): Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific; Science, v. 308, no. 5726, p. 1280–1284.

Watson, E. and Luckman, B.H. (2004): Tree-ring based reconstructions of precipitation for the southern Canadian Cordillera; Climatic Change, v. 65, p. 209–241.

Watson, E. and Luckman, B.H. (2005): Spatial patterns of preinstrumental moisture variability in the southern Canadian Cordillera; Journal of Climate, v. 18, p. 2847–2863.

Welch, D. (2002): Geoindicators for monitoring Canada's national parks: a proposal; Parks Canada, Ecosystem Science Review Report 017, 39 p.

Welch, D. (2005): What should protected areas managers do in the face of climate change; George Wright Forum, v. 22, p. 75–93.

Welch, D.W., Ishida, Y. and Nagasawa, K. (1998): Thermal limits and ocean migrations of sockeye salmon Oncorhynchus nerka: long-term consequences of global warming; Canadian Journal of Fisheries and Aquatic Sciences, v. 55, p. 937–948.

Wenzel R.P. (1994): A new Hantavirus infection in North America; New England Journal of Medicine, v. 330, p. 1004–1005.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R. and Swetnam, T.W. (2006): Warming and earlier spring increase western U.S. forest wildfire activity; Science, v. 313, no. 5789, p. 940–943.

Wheatley, M.A. (1998): Social and cultural impacts of environmental change on Aboriginal peoples in Canada; International Journal of Circumpolar Health, v. 57, supp. 1, p. 537–542.

Whitfield, P.H. and Cannon, A.J. (2000): Recent variations in climate and hydrology in Canada; Canadian Water Resources Journal, v. 25, p. 19–65.

Whitfield, P.H. and Cannon, A.J. (in press): Forthcoming changes in climate and hydrology of south-central BC, 1976–1995; Reviews of Fisheries Science.

Whitfield, P.H. and Taylor, E. (1998): Apparent recent changes in hydrology and climate of coastal British Columbia; *in* Mountains to Sea: Human Interaction with the Hydrologic Cycle, (ed.) Y. Alila; Proceedings of 51st Annual Canadian Water Resources Conference, June 10–12, 1998, Cambridge, Ontario, p. 22–29.

Whitfield, P.H., Bodtker, K. and Cannon, A.J. (2002a): Recent variations in seasonality of temperature and precipitation in Canada, 1976–1995; International Journal of Climatology, v. 22, p. 1617–1644.

Whitfield, P.H., Cannon, A.J., Wang, J.Y. and Reynolds, C.J. (2003): Modelling streamflows in present and future climates — examples from rainfall/snowmelt streams in coastal British Columbia; Hydrological Science and Technology, v. 19, no. 1–4, p. 41–56.

Whitfield, P.H., Reynolds, C.J. and Cannon, A.J. (2002b): Modelling streamflows in present and future climates — examples from Georgia Basin, British Columbia; Canadian Water Resources Journal, v. 27, no.4, p. 427–456.

Whyte, J. (2006): Extreme weather impacts on Provincial Emergency Programme (PEP) and public safety; Canadian Water Resources Association Conference, Victoria, BC.

Wieczorek G.F. and Glade, T. (2005): Climatic factors influencing occurrence of debris flows; *in* Debris-Flow Hazards and Related Phenomena, (ed.) M. Jakob and O. Hungr; Praxis and Springer, Berlin–Heidelberg–New York, p. 325–362.

Williams, B. (2005): Southern salmon fishery, post-season review 2004, part I: Fraser River sockeye report; Fisheries and Oceans Canada, 91 p., <http://www-comm.pac.dfo-mpo.gc.ca/publications/2004psr/default_e.htm>, [accessed May 18, 2007].

Willows, N.D. (2005): Determinants of healthy eating in Aboriginal peoples in Canada; Canadian Journal of Public Health, v. 96, supplement 3, p. S32–36.

Wolter, K. and Timlin, M.S. (1993): Monitoring ENSO in COADS with a seasonally adjusted principal component index; Proceedings of the 17th Climate Diagnostics Workshop, Norman, Oklahoma, NOAA/N MC/CAC, National Severe Storms Library, Oklahoma Climate Survey, Cooperative Institute for Mesoscale Meteorological Studies and the School of Meteorology, University of Oklahoma, p. 52–57.

Wolter, K. and Timlin, M.S. (1998): Measuring the strength of ENSO — how does 1997/98 rank?; Weather, v. 53, p. 315–324.

Woods, A.J., Coates, K.D. and Hamann, A. (2005): Is an unprecedented Dothistroma needle blight epidemic related to climate change? Bioscience, v. 9, p. 761–769.

Woodward, A., Hales, S., Litidamu, N., Phillips, D. and Martin, J. (2000): Protecting human health in a changing world: the role of social and economic development; Bulletin of the World Health Organization, v. 78, no. 9, p. 1148–1155, <http://www.who.int/docstore/bulletin/pdf/2000/issue9/bu0649.pdf>, [accessed May 18, 2007].

Wright, C.A., Dallimore, A., Thomson, R.E., Patterson, R.T. and Ware, D.M. (2005): Late Holocene paleofish populations in Effingham Inlet, British Columbia, Canada; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 224, p. 367–384.

Wright, H. (2004): Management plan for experimental reintroduction of sockeye into Skaha Lake: proposed implementation, monitoring and evaluation; unpublished report prepared for Colville Confederated Tribe by Okanagan Nation Alliance Fisheries Department, Westbank, BC, 17 p.

Wright, I.J., Reich, P.B., Cornelissen, J.H.C., Falster, D.S., Groom, P.K., Hikosaka, K., Lee, W., Lusk, C.H., Niinemets, U., Oleksyn, J., Osada, N., Poorter, H., Warton, D.I. and Westoby, M. (2005): Modulation of leaf economic traits and trait relationships by climate; Global Ecology and Biogeography, v. 14, no. 5, p. 411.

Yin, Y. (2001): Designing an integrated approach for evaluating adaptation options to reduce climate change vulnerability in the Georgia Basin; report submitted to Climate Change Impacts and Adaptation Program, Natural Resources Canada, 50 p., <http://adaptation.nrcan.gc.ca/projdb/pdf/80_e.pdf>, [accessed July 24, 2007].

Young, N. (2006a): New economic spaces and practices in coastal British Columbia; Ph.D. thesis, Department of Sociology University of British Columbia Vancouver, BC.

Young, N. (2006b): Distance as a hybrid actor in rural economies; Journal of Rural Studies, v. 22, no. 3, p. 253–266.

Zebarth, B., Caprio, J., Broersma, K., Mills, P. and Smith, S. (1997): Effect of climate change on agriculture in the British Columbia and Yukon; *in* Responding to Global Climate Change in British Columbia and Yukon, Volume 1, Canada Country Study: Climate Impacts and Adaptation, (ed.) E. Taylor and B. Taylor; Environment Canada and BC Ministry of Environment, Lands and Parks.

Zektser I.S. and Loaiciga, H.A. (1993): Groundwater fluxes in the global hydrologic cycle: past, present, and future; Journal of Hydrology, v. 144, p. 405–427.

Zhang, Q.B. and Hebda, R.J. (2005): Abrupt climate change and variability in the past four millennia of the southern Vancouver Island, Canada; Geophysical Research Letters, v. 32, doi:10.1029/2005GL022913.

Zhang, X., Harvey, D.K., Hogg, W.D. and Yuzyk, T.D. (2001a): Trends in Canadian streamflow; Water Resources Research, v. 37, no. 4, p. 987–998.

Zhang, X., Hogg, W.D. and Mekis, É. (2001b): Spatial and temporal characteristics of heavy precipitation events over Canada; Journal of Climate, v. 14, p. 1923–1936.

Zhang, X., Vincent, L.A., Hogg, W.D. and Niitsoo, A. (2000): Temperature and precipitation trends in Canada during the 20th century; Atmosphere-Ocean, v. 38, no. 3, p. 395–429