CHAPTER 6: PERSPECTIVES ON CANADA'S WEST COAST REGION

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Recommended Citation:
Vadeboncoeur, N. (2016): Perspectives on Canada's West Coast region; *in* Canada's Marine Coasts in a Changing Climate, (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer Clarke; Government of Canada, Ottawa, ON, p. 207-252.

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KEY FINDINGS

Coastal British Columbia is geographically, ecologically and socially diverse. The climate changes anticipated for this region, and their impacts, are similarly varied. Although large urban centres, small rural settlements and First Nations communities will experience climate change in different ways, several key findings are relevant to the region as a whole:

- **Sea-level rise will not affect all areas of the British Columbia coast equally, largely due to differences in vertical land movement.** The largest amounts of relative sea-level rise are projected to occur on the Fraser Lowland, southern Vancouver Island and the north coast. Planning guidance for sea-level rise developed by the British Columbia government provides planning levels that slightly exceed the peak values (95th percentile) of the sea-level projections at 2050. This could be considered a margin of safety that allows for possible additional sea-level rise arising from factors with significant uncertainty, such as contributions from the Antarctic Ice Sheet.
- **Storm-surge flooding presents a greater threat to coastal communities than sea-level rise alone.** Coastal communities are already coping with extreme water levels associated with climate variability (e.g., El Niño/La Niña Southern Oscillation) and storm-surge flooding. The risks associated with these events are expected to increase as sea level rises. Residential, commercial, institutional and municipal property and infrastructure in the region are vulnerable, and communities have begun to take action to reduce the risk through adaptation measures such as shoreline protection.
- **Marine ecosystems will be affected as species move northward in response to warmer water.** Southern species will expand their range northward into British Columbia as the ocean warms, while species that today inhabit the south coast region, including salmon, will also migrate north. In the southern part of the province, warmer ocean-surface temperatures will decrease the habitable range of shellfish and changing ocean acidity will affect their reproductive success. Adaptation in the commercial-fisheries sector will involve shifting the types of species being fished and relocating operations. First Nations, who rely strongly on salmon for cultural uses, often have fewer options for adaptation to changes in distribution and abundance of fish species.
- **Changing precipitation patterns will affect summer water availability and the timing of salmon runs in some watersheds.** Winter precipitation is expected to increase overall, with more falling as rain and less as snow. Less precipitation is expected during the summer and this, combined with reduced snowpack, will decrease the amount of water available for some regions in late summer and autumn. River levels will decrease during this period and water temperature is likely to increase as a result. Increased river temperature would affect the timing of salmon runs because these fish do not enter rivers until water temperatures cool to approximately 15°C.
- **Climate change adaptation is gaining momentum in British Columbia.** Governments have been moving forward on climate change adaptation, particularly regarding sea-level rise and coastal-flooding issues. Notable projects include a cost assessment of upgrading Metro Vancouver's dike system; a risk study for sea-level rise in the Capital Regional District; the City of Vancouver's new Flood Construction Level that considers sea-level rise; the placement of boulders below the low-tide level off the West Vancouver shore to mitigate storm-surge impacts; and the development of a Sea-Level Rise Primer for local governments.

1 INTRODUCTION

Western Canada features more than 27 200 km of coastline, all within the Province of British Columbia (Figure 1). Coastal landscapes range from low-lying deltas to mountainous fiords that host diverse ecosystems, economies and cultures. Climate and weather patterns along Canada's Pacific coast are highly variable, due largely to the region's complex and varied physiography (Section 2; Demarchi, 2011). Much of the British Columbia coastline consists of deeply indented fiords with substantial relief, but the two largest concentrations of population are located on the Fraser Lowland, which includes large regions, such as the Fraser River delta, with elevations near sea level, and on southern Vancouver Island, a region of relatively subdued topography. The major urban areas of the southwestern mainland and southern Vancouver Island give way to smaller communities and remote settlements, many within the traditional territories of numerous First Nations.

FIGURE 1: Geographic extent of the West Coast region.

Although fishing and forestry often feature prominently in discussions about the provincial economy and energy is seen as playing an important role in BC's future, primary industries (agriculture, forestry, fishing, mining and energy) make up only 7.7% of provincial GDP (BC Stats, 2014). British Columbia is also a largely urban province, with about 75% of its population residing within Metro Vancouver (BC Stats, 2013a) on the southwest mainland, and in the Capital Regional District on southern Vancouver Island. The construction and manufacturing industries are equal in size to the primary industries, and service-producing industries overshadow them all, making up 75.5% of provincial GDP (BC Stats, 2014).

The West Coast has two major commercial hubs, Port Metro Vancouver and Vancouver International Airport, which together contribute 6.4% of provincial GDP and generate $34 billion in total annual economic output (Intervistas Consulting Inc., 2009; Vancouver Airport Authority, 2012; Port Metro Vancouver, 2013). These centres of trade, along with the Port of Prince Rupert, link Canada with its trading partners in Asia, making British Columbia the 'Gateway to the Pacific'.

Although the modern provincial economy is diverse, the economies of many coastal communities remain strongly tied to ecosystems—fisheries, forestry and nature tourism. There are more than 170 cities, towns and villages (including unincorporated areas) along the western coast, and many of these are vulnerable to environmental changes that affect the resources and ecosystem services that residents rely upon for their livelihoods. Some of these communities have already experienced stress from the decline of the forestry and fishing industries. The result has been unemployment and economic migration to larger urban centres. People living in coastal communities with cultural ties to specific areas can experience high levels of psychological stress related to ecosystem changes that affect the viability of small, isolated, resource-dependent settlements.

The contrast between globally integrated, wealthy urban centres and resource-dependent rural communities is important for understanding how people perceive, and experience, climate change impacts. Socio-economic differences, such as wealth and the dependence on resources for income, can contribute to varying levels of climate vulnerability (e.g., Adger and Kelly, 1999; Thomas and Twyman, 2005). However, this dichotomy should not be overstated. Northern communities, such as Kitimat and Prince Rupert, play increasingly important roles in the BC export market, and many northern coastal jobs are fully integrated with national and global economies. Therefore, although it is possible to identify differences in regional vulnerability trends, the economic and social diversity of BC communities suggests that a nuanced, community-based approach to adaptation is needed.

Studies linking projected changes in climate to impacts on human activities and health suggest that sea-level rise, changes in the nature, timing and intensity of storms and precipitation events, and the altered distribution of marine species present the greatest concerns in coastal British Columbia. This is reflected in the focus of adaptation work going on in the province. Efforts to understand and address climate change impacts in British Columbia have been underway for more than 25 years (e.g., City of Vancouver, 1990). However, a strong, province-wide focus on adaptation is relatively recent, beginning within the last 10 years. Recognition of the need for adaptation has been accelerating since then.

1.1 SCOPE AND ORGANIZATION OF THIS CHAPTER

This chapter addresses the question "What do we know about climate change in coastal British Columbia and what is being done to adapt?" It presents the current state of knowledge by focusing on areas where there has been the most progress, in terms of both research and work. This includes fisheries, community impacts and responses, and strategically important built environments (e.g., major export hubs). Despite the growing importance of tourism and recreation for coastal economies, less information is available on the impact of climate change on these sectors. By contrast, many coastal local governments, supported by an increasing body of literature on adaptation, have begun to address climate change. These numerous examples allow an assessment of adaptation planning in the region.

While important gaps in understanding are acknowledged, the chapter focuses on what we have learned during the last decade, and in particular the years since the previous assessment of Walker and Sydneysmith (2008). In this way, the chapter profiles the rapid progress of both climate science and of government interest in adaptation.

The chapter first assesses the current state of knowledge regarding the changes in climate anticipated for BC's coastal waters and landscapes, from the Coast Mountains westward. It begins with a review of observed and projected changes in atmospheric, hydrological and oceanographic conditions to the year 2100 (Section 2). Next, it discusses how these changes are expected to affect ecological and human systems along the coast (Sections 3 and 4). The scientific and technical literature does not cover all issues or areas evenly across the West Coast region. For example, sea-level rise and its potential impact on Metro Vancouver have received substantial attention, whereas communities along the north and central coast have received less attention. Recognizing this asymmetry, and in order to broaden the relevance of available information to a coast-wide audience, this chapter places a strong focus on the process of adaptation.

The chapter concludes with a discussion of the state of adaptation in coastal British Columbia. Case studies from a range of coastal municipalities and sectors are provided to illustrate the various approaches to adaptation planning taking place throughout the region.

2 CHANGING REGIONAL CLIMATE

The climate of coastal British Columbia is characterized by relatively dry summers and wet winters, with most storm activity occurring in the winter months (Mesquita et al., 2010). Temperatures are mild and vary little compared to the rest of Canada. Daily mean temperature remains above freezing throughout the year (except at high elevations), and winter and summer mean temperatures rarely differ by more than 15°C.

In contrast to temperature, precipitation shows strong regional and seasonal variability. Average annual precipitation in the region ranges from less than 900 mm on eastern Vancouver Island, the Gulf Islands and eastern Haida Gwaii to more than 3500 mm on western Vancouver Island, with even greater amounts at higher elevations (e.g., more than 5000 mm in the Coastal Mountains of the mainland). Oceanic low-pressure systems dominate in winter, with heavy precipitation arising from the moist, mild air being pushed onto the south and central coast (Demarchi, 2011). In summer, high-pressure systems tend to dominate the region, resulting in drier conditions along much of the coast (Demarchi, 2011).

An important aspect of the regional climate, unique in Canada to the West Coast region, is the phenomenon of 'Atmospheric Rivers' (colloquially referred to as the 'Pineapple Express'). Atmospheric rivers are defined as "long narrow streams of high water vapour concentrations in the atmosphere that move moisture from tropical regions towards the poles across the mid latitudes" (PCIC, 2013a, p. 2). Atmospheric rivers are responsible for the most extreme rainfall events in the West Coast region (e.g., Ralph and Dettinger, 2012). The intense rainfall associated with atmospheric rivers can result in flooding and landslides, and potentially in costly damage to coastal communities (Lancaster et al., 2012; PCIC, 2013a).

The climate of coastal British Columbia shows significant variability at the scale of years and decades, due largely to the important influence of two climate cycles: the El Niño/La Niña Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; *see also* Chapter 2; Moore et al., 2010). The ENSO has a cyclicity of about 3–5 years. In warm El Niño years, air heated by above-average sea-surface temperatures moves northward from tropical regions into North America, where it remains for several months. The effect of this on the West Coast region is warmer winters with less precipitation. The cold phase, La Niña, brings air cooled by below-normal sea-surface temperatures north from the tropics. This also lasts for several months and leads to colder winters and cooler waters off the coast of BC (e.g., Shabbar et al., 1997; Fleming and Whitfield, 2010).

The other climate cycle, the PDO, is also a warm/cool cycle. However, unlike ENSO, each PDO cycle is measured in decades rather than months, repeating every 40–60 years. Sea-surface temperatures in the north Pacific, which alternate from periods of relative warm to periods of relative cool, drive this cycle. These cyclical changes in ocean temperature affect air temperature in BC because the prevailing winds, influenced by the jet stream, move over north Pacific waters before blowing over the West Coast.

Understanding the strong influence of ENSO and PDO on British Columbia's climate is crucial for understanding climate change in the region. For example, average temperatures in coastal British Columbia are slowly creeping upward, at fractions of a degree per decade (PCIC, 2013b, c). At the same time ENSO and PDO are causing relatively strong fluctuations of several degrees that last from months to years, making it more difficult to discern a climate change signal (*see* Chapter 2).

2.1 TEMPERATURE

Average annual temperatures throughout the West Coast region have increased by 1.3°C during the past century (0.12–0.13°C per decade; PCIC, 2013b, c). This is slightly greater than the increase in global mean surface temperature during the same period (e.g., IPCC, 2013) but less than the average for Canada as a whole (Bush et al., 2014; *see also* Chapter 2). Since 1951, the rate of warming along the West Coast has increased to approximately 0.2°C per decade (Figure 2). Warming has been observed in all seasons; however, since 1951, temperature has increased the fastest during summer (0.22–0.26°C per decade; PCIC, 2013b, c).

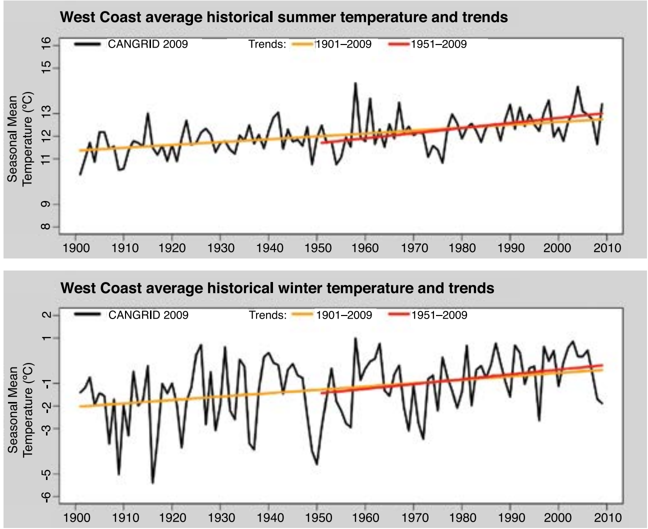

FIGURE 2: Historical temperature trends (1901–2009) for the West Coast region of British Columbia (PCIC, 2013b, c). All trends except winter (1951–2009) are statistically significant at the 95% confidence level. Trends for the south coast, which includes Vancouver, are very similar (PCIC, 2013b).

Projections of future changes in temperature, precipitation and other climate variables are available online at provincial and regional scales from the Pacific Climate Impacts Consortium (www.pacificclimate.org; *see also* www.Plan2Adapt.ca). Temperature projections suggest that warming will continue in all seasons, with the greatest increases in year-over-year temperature continuing to occur during summer. Annual warming of about 1.4°C is projected by the 2050s and 2.3°C by the 2080s (relative to the 1961–1990 average), based on consideration of two Intergovernmental Panel on Climate Change (IPCC) Special Reports on Emissions Scenarios (IPCC, 2000). These increases in temperature are less than those projected for Canada as a whole.

2.2 PRECIPITATION

Trends in average seasonal precipitation have remained stable for the West Coast for the past century. Although records suggest that average precipitation has been increasing during that time, few of these trends are statistically significant (PCIC, 2013b, c). Changes are most likely explained by the high natural variability of precipitation in the region. However, clear signals of the influence of climate change on precipitation may emerge by the 2080s (PCIC, 2013b).

Climate change will likely have little effect on the average amount of precipitation the West Coast region experiences in a given season or year. However, it may affect the timing of precipitation and is likely to alter both its form (rain or snow) and intensity (how much at a time; Whitfield and Taylor, 1998). By the 2080s, average precipitation may increase by roughly 10%, relative to a 1961–1990 baseline, in all seasons except summer, where a 10% decrease is projected (PCIC, 2013b, c). This change would be small relative to historical variability, meaning that the average precipitation levels are expected to remain in line with what the region has experienced during the past century.

Higher winter and springtime temperatures will reduce the percentage of total precipitation occurring as snowfall. By the 2050s, winter snowfall is projected to decrease by about 25% and spring snowfall by about 50% (PCIC, 2013b, c). For the 2080s, the projected reduction in spring snowfall may reach 72% (compared with the 1961–1990 baseline). Less snow and more rain would lead to faster runoff and could contribute to water-scarcity issues because less water will be stored as snow and ice (Section 2.3).

An emerging concern for coastal British Columbia is the potential for more frequent and/or more intense extreme-rainfall events. The West Coast receives 20–25% of its annual precipitation in heavy-rainfall events resulting from atmospheric rivers. The frequency of atmospheric-river events is expected to increase for coastal BC during the period 2041–2070 under a high-emissions scenario

(Cannon et al., work in progress). This would increase the risk of flooding, landslides and sediment loading in drinking-water reservoirs.

Since 2001, British Columbia has experienced at least one flooding event per year caused by extreme weather or precipitation, including a 2009 storm that caused $9 million in damage, and one in 2012 that cost nearly $16 million (PCIC, 2013a). Work is underway to better understand, predict and manage the impacts associated with atmospheric rivers through improved data collection, forecasting and public participation in reporting extreme-rainfall events, the damage they cause and successful adaptation strategies (PCIC, 2013a).

2.3 HYDROLOGY

Projected changes in both temperature and precipitation patterns will result in changes to stream flow in coastal watersheds. Natural climate variability associated with ENSO and PDO will also play a role. As a result, future trends in the distribution and circulation of water within British Columbia's watersheds will be influenced by a combination of long-term climate change and short- to medium-term climate variability.

The distribution and circulation of water in British Columbia's coastal watersheds can be classified into three hydrological regimes: rainfall dominated, snowmelt dominated and hybrid (both rainfall and snowmelt dominated; Wade et al., 2001; Fleming et al., 2007). Climate changes, such as increased temperature and more precipitation falling as rain (rather than snow), threaten to alter the current patterns of water accumulation and discharge. It is not clear what effect climate change will have on rainfall-dominated watersheds, which already exhibit considerable variability. For example, during the period 1976–2005, mean daily, maximum daily and mean annual streamflow has decreased in rainfall-dominated regimes on the south coast but increased on the north coast (Rodenhuis et al., 2009).

A region-wide trend of declining snowpack across BC and western North America has been observed during the past several decades (Mote, 2003; Mote et al., 2005; Rodenhuis et al., 2009; Stewart, 2009). Earlier spring snowmelt and a declining proportion of winter precipitation occurring as snow have contributed to this decline (Stewart et al., 2005; Knowles et al., 2006; Stewart, 2009). Maintaining snowpack is important because this affects the amount of water that is stored for release during the summer and autumn.

Glaciers play a similar role in water storage and have been predominantly in a state of retreat since the mid-18th century as a result of rising temperatures. Glacier surveys throughout the Coast Mountains of BC indicate that the recent rate of glacier loss is nearly double that of previous decades (Schiefer et al., 2007; Bolch et al., 2010). In some basins, this reduced ice cover is associated with decreased summer flows (Moore and Demuth, 2001; Cunderlik and Burn, 2002; Stahl and Moore, 2006). This is consistent with the trend observed throughout western North America of changed timing and seasonality for the flow of snowmelt-dominated rivers (Stewart et al., 2005). Glaciers will continue to retreat as the climate warms. For example, Bridge Glacier, the source of the Bridge River, which provides 6–8% of BC's hydroelectric generating capacity, is expected to lose roughly half of its current area by the end of the century (Stahl et al., 2008).

Long-term trends suggest that coastal BC will experience decreased summer flows in glacier- and snowmelt-dominated watersheds. However, historical streamflow responses suggest that there will continue to be considerable year-to-year regional variability in summer water availability (Fleming et al., 2007). For example, while summer discharge has increased in the glaciated basins of the Stikine and Iskut rivers (Moore et al., 2009), rivers throughout the Fraser basin, including the main stem, have experienced high interannual variability in streamflow in recent decades, particularly during the spring and summer (Déry et al., 2012).

Summer water scarcity is already a concern for some coastal communities, such as those in the Cowichan Valley Regional District and the Sunshine Coast Regional District, and seasonal reductions in potable water supply (e.g., surface-water and groundwater sources) could become a concern for more communities as climate change progresses. Increasing, periodic water scarcity during the summer is anticipated in snowmelt-dominated regimes and, in particular, hybrid rain-snow regimes (Case Study 1).

CASE STUDY 1

PROJECTED HYDROLOGICAL CHANGES IN THE CAMPBELL AND FRASER RIVER WATERSHEDS

(summarized from Schnorbus et al. [2014] and Shrestha et al. [2012]; see these references for more detailed discussion of methodology and results)

The Campbell River and Fraser River watersheds drain into the Strait of Georgia from central Vancouver Island and the lower mainland, respectively (Figure 3). These basins together support a range of ecosystems, including major salmon-spawning grounds.

The Campbell River watershed is a mountainous basin on central Vancouver Island that covers 1755 km^2 and extends to 2200 m above sea level. The basin has a hybrid snowmelt-rainfall runoff regime characteristic of many

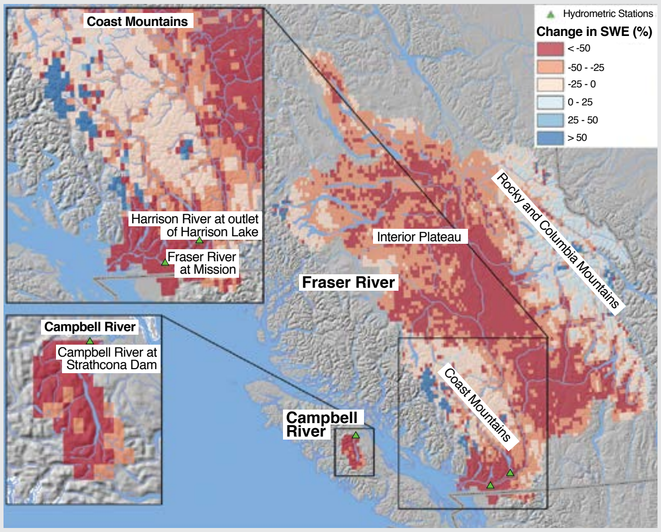

FIGURE 3: Projected mid-century (2041-2070) change in April 1st snow water equivalent (SWE) for the Campbell River and Fraser River basins (Schnorbus et al., 2014). Values are based on the median change from the 1961-1990 period for the A1B scenario (which assumes medium future anthropogenic radiative forcing).

coastal watersheds in BC, with runoff peaks in both fall and spring. The Fraser River system is the largest drainage basin in British Columbia, covering an area of 230 000 km^2. The basin extends to about 4000 m above sea level and has average annual precipitation ranging from 200 to 5000 mm, with areas of higher elevation experiencing greater precipitation. Although much of the Fraser River basin lies in the interior of BC, it supplies the largest pulse of fresh water to the BC coast (Morrison et al., 2012). The majority of the Fraser River basin, including the main stem, is a snowmelt-dominated regime with annual runoff dominated by spring freshet.

Hydrological modelling was used to simulate both a 30-year baseline (1961–1990; or the 1970s) and a future (2041–2070; or the 2050s) hydrological regime in both watersheds. An ensemble of eight global-climate models (GCMs) and three emissions scenarios were used to project changes in regional climate. Statistical downscaling of the GCM output to be compatible with the high spatial resolution of the hydrology model was achieved through bias corrected spatial disaggregation. Data for the Fraser River at Mission and the Campbell River at Strathcona Dam were naturalized to remove the influence of regulation.

Significant changes in winter snow accumulation during the 2050s are projected for both basins (Figure 3). A decrease in snow accumulation is expected throughout the Campbell River basin. A decrease in spring snow cover is anticipated for the Fraser River basin, with the exception of increased snow being projected for parts of the Rocky, Columbia and Coast Mountains.

In addition to warmer temperatures and increased precipitation in all seasons except summer, these changes in snow cover will result in changes to streamflow. In the Fraser River basin, total annual flow is projected to increase under most scenarios. Winter and spring flows should increase, whereas summer and autumn flows could either increase or decrease (Figure 4).

By the 2050s, earlier snowmelt is projected to advance the timing of the annual peak flow for the Fraser River. For example, peak flow could be 14–18 days earlier at Mission and 29–35 days earlier in the Harrison River sub-basin. In the Campbell River watershed, projected changes in mean annual streamflow are negligible, but significant seasonal variation is expected. By the mid-21st century, the Campbell River is projected to change from a hybrid regime to a rainfall-dominated regime, with increases in monthly streamflow from October to April and decreases from May to September (Figure 4).

2.4 SEA LEVEL

Ocean-water levels vary on daily to decadal time scales due to a variety of atmospheric and oceanographic effects, including storm surges induced by low atmospheric pressures and climate-variability cycles, such as ENSO and PDO (e.g., Crawford et al., 1999; Barrie and Conway, 2002; Abeysirigunawardena and Walker, 2008, Section 2; Thomson et al., 2008). During an ENSO or PDO cycle, changes in the density of ocean water brought about by water-temperature changes affect the elevation of the sea surface by tens of centimetres, while the magnitude of a storm surge can reach 1 m (Thomson et al., 2008). Large waves generated by strong winds can exacerbate coastal flooding and erosion during a storm-surge event. In the short term (years), it is this variability in sea levels and waves that will cause coastal flooding. The slow rise in mean sea level over decades described below significantly increases the frequency of extreme water events (*see* Chapter 2).

Over a longer time period, changes in relative sea level across the West Coast region show significant variability. During the past 50 years, for example, sea level rose by 3.1 cm at Victoria and 2.0 cm at Vancouver, but declined by 8.4 cm at Tofino (Bornhold and Thomson, 2013). All three communities are within approximately 220 km of one another. A dominant factor affecting relative sea-level change in British Columbia, as with the rest of Canada, is vertical land motion, but other factors also play a role, as discussed in Chapter 2. Vertical land movements in British Columbia arise from a combination of tectonic activity due to the interactions of the Juan de Fuca and Pacific oceanic

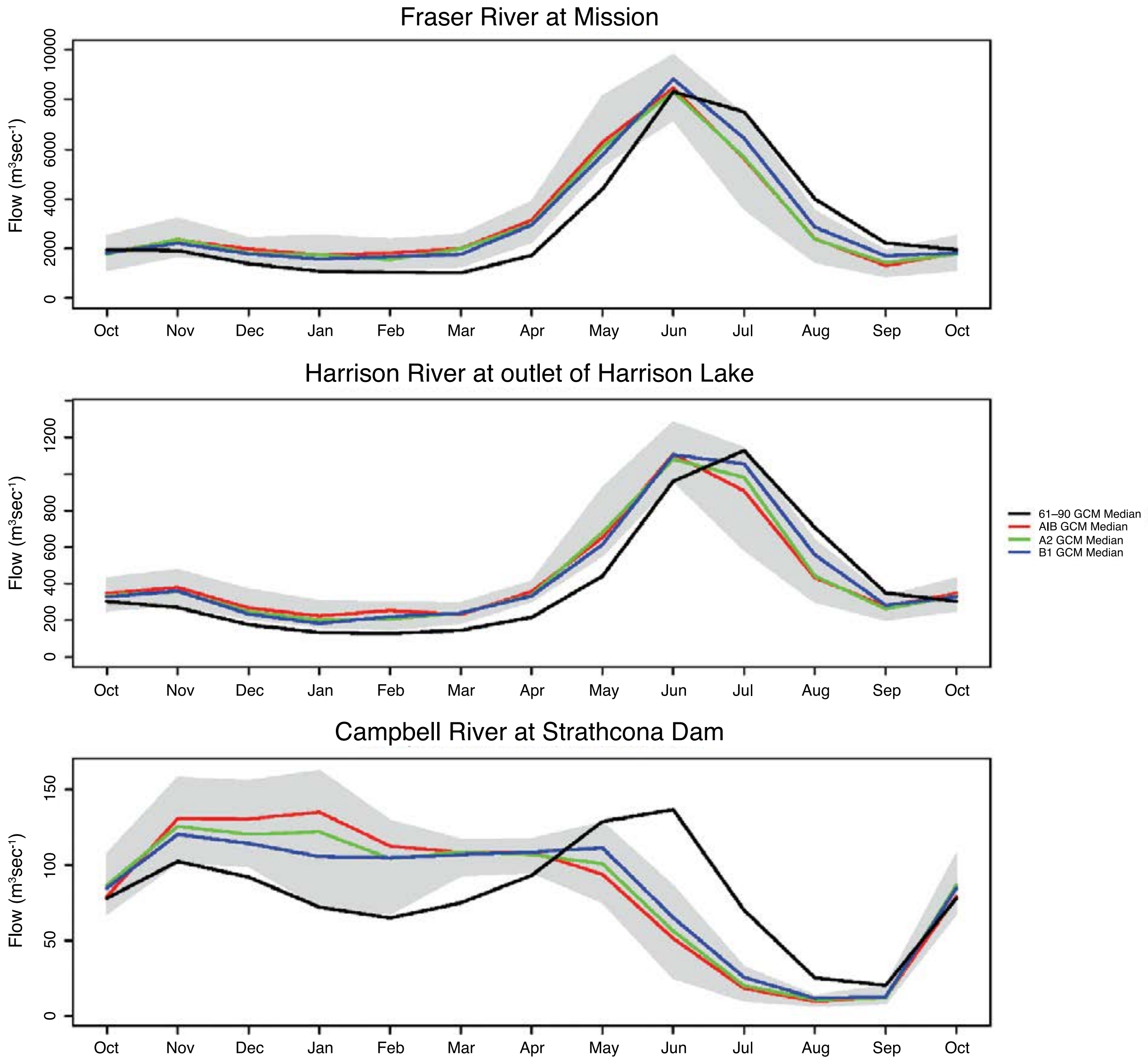

FIGURE 4: Projected change in monthly streamflow for the Fraser River at Mission, the Harrison River at the outlet of Harrison Lake, and the Campbell River at Strathcona Dam. Note that streamflow for the Campbell River represents natural conditions (i.e., absent the effects of flow regulation). Results show median streamflow changes for each scenario (A1B, A2 and B1) and the projection range (grey shading) for 23 individual projections.

plates with the North America plate, the land moving upward in response to the weight removed when the glaciers of the last ice age melted (glacial isostatic adjustment; *see* Chapter 2), and present-day ice-mass changes in the Coast Mountains and the Gulf of Alaska. On the Fraser River delta, sediment compaction contributes to land subsidence (Mazzotti et al., 2009). Global Positioning System (GPS) observations show that the land is rising faster on the west coast of Vancouver Island than at Victoria and Vancouver (Mazzotti et al., 2008), explaining why sea level has been observed to fall at Tofino during the last 50 years but rise at Victoria and Vancouver.

Global mean sea level is expected to rise by 44–74 cm (median values, relative to 1986–2005) by the year 2100 (IPCC, 2013), and larger increases cannot be ruled out (Chapter 2). If the West Antarctic Ice Sheet were to experience accelerated discharge this century due to instability of the marine-based portions, which is a possible but unlikely scenario (IPCC, 2013), global sea level could increase by additional tens of centimetres and surpass one metre.

Projected relative sea-level change in British Columbia coastal waters (Figure 5) exhibits regional variability similar to historical patterns of sea-level change, again primarily due to differences in vertical land motion. Other effects that also contribute to regional variability include the decreased gravitational pull of melting glaciers on nearby ocean waters and changes to ocean currents that affect the topography of the sea surface. Projected median sea-level change at the year 2100 for the high-emissions scenario (RCP8.5) ranges from 50 to 70 cm on southern Vancouver Island, in the region surrounding the City of Vancouver and in northern coastal BC. The remainder of Vancouver Island and the adjacent mainland coast are projected to experience smaller amounts of relative sea-level rise, owing to their larger amounts of land uplift. Despite this regional variability, there is a general trend of projected relative sea-level rise along the West Coast of Canada, although uncertainties are sufficiently large that sea-level fall is possible for some scenarios at communities where land uplift is relatively large.

Sea-level projections through the 21st century are given in Figure 6 for four communities. The relative sea-level projections are smaller at locations with larger amounts of crustal uplift. Also shown are the sea-level allowances developed by the Province of British Columbia to define Flood Construction Levels (Ausenco Sandwell, 2011a, b), based on earlier investigations (Mazzotti et al., 2008; Thomson et al., 2008). The allowance is defined to be 50 cm at 2050 and 100 cm at 2100, and is corrected for local vertical land motion. The BC allowances lie above the projections of the Representative Concentration Pathway (RCP) scenarios but below the highest scenario featuring an augmented sea-level rise contribution from West Antarctica. Thus, they fully account for the range of likely (defined by the IPCC Fifth Assessment Report as 66–100% probability) projected sea-level change and account for a portion of additional, poorly constrained but possible sea-level rise.

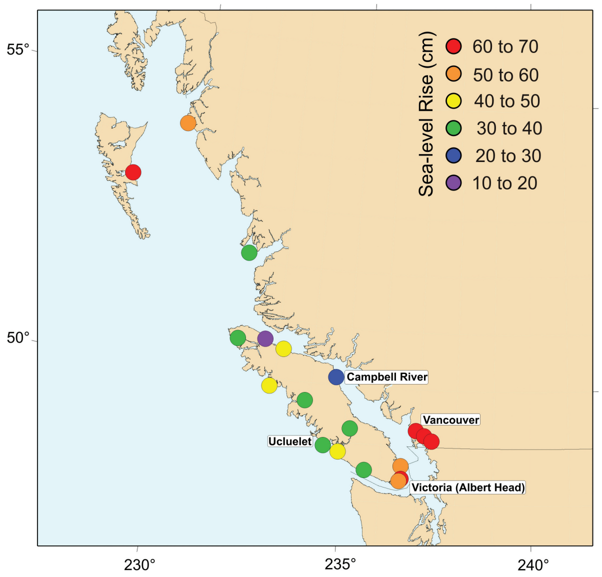

FIGURE 5: Projections of relative sea-level rise for the year 2100 for the median value of the high-emissions scenario (RCP8.5; after James et al., 2014–2015). See Chapter 2 for additional information on sea-level projections. Sea-level projections through the 21st century are given in Figure 6 for the four labelled communities, and projected changes for all sites are presented in Appendix A.

Changes in sea level will present a challenge to many of the roughly 170 coastal communities in British Columbia. For example, approximately 245 000 people in Metro Vancouver live in floodplains at risk from sea-level rise. Important regional and national infrastructure is also at risk. The Port of Metro Vancouver and Vancouver International Airport (YVR), both within several metres of sea level, directly support approximately 71 000 jobs in British Columbia (approximately 221 000 jobs overall) and contribute more than $34 billion in total economic output (Intervistas Consulting Inc., 2009; Vancouver Airport Authority, 2010). Sea-level rise could present challenges to proposed major industrial sites along the north coast, notably in the Kitimat, Prince Rupert and Stewart regions, which are potential energy-export hubs.

Many communities, businesses and local governments, and the Province of British Columbia, recognize the need to better understand and plan for sea-level rise. A more detailed discussion of the risks this presents to coastal communities, and a collection of case studies highlighting adaptation actions already under way, can be found in Section 4 of this chapter.

3 CHANGES TO ECOSYSTEM STRUCTURE AND FUNCTION

Climate change will affect coastal ecosystems in British Columbia. Increased water temperature and changes to ocean acidity, salinity and dissolved oxygen content will together alter ecosystem structure and function. The warm/cool phases of the ENSO and PDO cycles (Section 2) produce short-term changes in water temperatures off the coast of British Columbia and provide a preview of how warmer water may affect coastal ecosystems.

Climate change may have both positive and negative effects on BC's coastal marine biodiversity. For example, an expected increase in upwelling from the California Current (Snyder et al., 2003; Black et al., 2014) could increase the availability of nutrients and lead to higher rates of reproduction for some forms of marine life. However, decreased oxygen and increased acidity (Kleypas et al., 2005; Chan et al., 2008; Ianson, 2008; Widdicombe and Spicer, 2008; Miller et al., 2009) would have negative impacts on other species, particularly shellfish. The most important change may be increased water temperature in both fresh-water (rivers) and marine ecosystems. This could negatively impact salmon by reducing both their reproductive success and the survival chances of salmon fry. Higher water temperatures may also cause a northward shift of the north-south ecological transition zone and, as a result, introduce new species to BC's coastal waters.

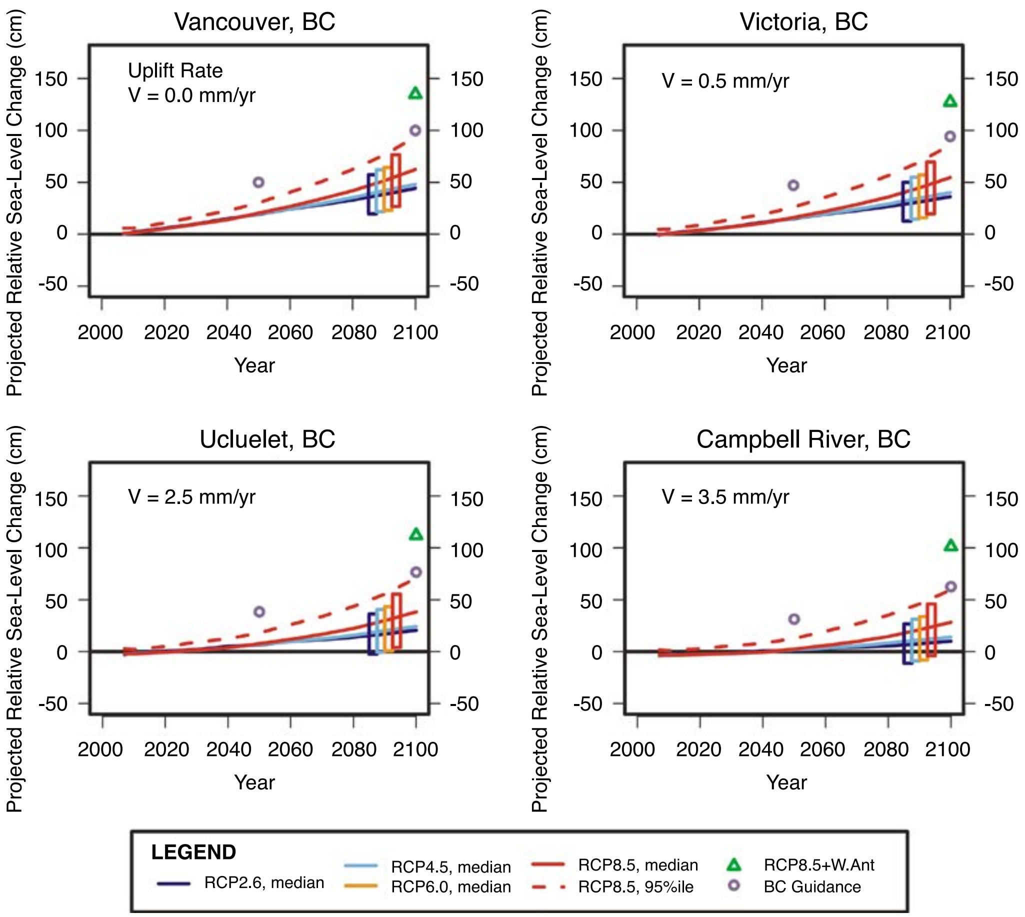

FIGURE 6: Projected relative sea-level change through the 21st century for selected communities in British Columbia (*after* James et al., 2014-2015). RCP2.6 is a low-emissions scenario, RCP6.0 is an intermediate-emissions scenario and RCP8.5 is a high–emissions scenario. The projected value at 2100 is also given for the high-emissions plus Antarctic ice-sheet reduction scenario, an augmented scenario in which West Antarctica contributes an additional 65 cm to the median projected value of the high-emissions scenario (RCP8.5+W.Ant; green triangle). Rectangles show the 90% confidence interval (5–95%) of the average projection for the period 2081-2100 and include RCP6.0. The dashed red line gives the 95th percentile value for the high-emissions scenario. Vertical land motion is given to the nearest 0.5 mm/year in each panel. The allowance for sea-level rise (BC Guidance) specified by the Government of British Columbia is also given (Ausenco Sandwell, 2011b, c). See Chapter 2 for further explanation of scenarios. Abbreviation: 95%ile, 95th percentile.

3.1 MARINE CONDITIONS: CIRCULATION, ACIDIFICATION AND SALINITY

British Columbia may be particularly vulnerable to ocean acidification, relative to other coastal environments in Canada, over the long term because the north Pacific is already very acidic. If the water were slightly more acidic, it would be termed 'corrosive' because calcium carbonate, the building block of shells, would begin to dissolve (Feely et al., 2004). Long-term projections of the risk that increased ocean acidity presents to marine life are not currently possible for the coastal region (Ianson, 2013). This is due, in part, to the fact that processes contributing to ocean acidity can vary region by region and can be hard to predict in expansive areas such as the Strait of Georgia. There are also data limitations related to the highly variable marine circulation (Chavez et al., 2007; Nemcek et al., 2008).

Climate change will influence ocean acidity through changes in temperature, precipitation and streamflow. Climate change can affect nearshore circulation by changing the amount of fresh water that flows into the ocean. As more precipitation falls as rain (rather than as snow) and glaciers and snowpack continue to melt, the fresh-water flow of coastal rivers will increase, particularly in the spring and fall (Section 2.3). Long-term reductions in winter snowpack have already affected the hydrology of the Fraser River (Morrison et al., 2002) by decreasing the volume of water available for release during the summer and, in turn, changing annual patterns of nearshore salinity in the Strait of Georgia. Decreased salinity of surface waters, related to increased regional precipitation (BC Ministry of Environment, 2007; Rodenhuis et al., 2007; Walker and Sydneysmith, 2008) and warming sea-surface temperatures (Freeland et al., 1997; Whitney et al., 2007; Freeland, 2013) result in a decrease in dissolved oxygen.

3.2 FRESH-WATER CONDITIONS: RIVER TEMPERATURE

Water temperatures in the Fraser River have warmed by approximately 1.5°C since the 1950s (Martins et al., 2011) and could increase by an additional 1.9°C by 2100 (Morrison et al., 2002). Such changes to river temperature can negatively impact fish populations, particularly salmon, that are sensitive to river temperature at both ends of their life cycle (spawning salmon do not enter rivers that are too warm, and hatchling mortality is increased by high water temperatures; see Rand et al., 2006; Martins et al., 2011). River temperatures may increase across the province as mean annual air temperature rises and glaciers and snowpack decline. Reduced summer flow in some rivers could also lead to warmer water.

Increased river temperature can have a negative effect on riverine ecosystems and the benefits humans derive from them through its effects on micro-organisms (Farrell and Rose, 1967), amphibians and other poikilotherms (i.e., animals whose body temperatures fluctuate; Fry, 1967), fish (Elliot, 1994; Rand et al., 2006; Martins et al., 2011), insects (Ward, 1992), water quality (Morrill et al., 2005), and businesses and recreation (McMichael and Kaya, 1991). Although river temperature will be affected by climate change, there are many other human-driven factors that can influence this, and research is beginning to further our understanding of these non-climate drivers (Webb et al., 2008).

3.3 MARINE ECOLOGICAL CHANGES

Climate change will impact marine ecology in coastal British Columbia by altering the vertical, shoreward (Brodeur et al., 2006) and latitudinal (Cheung et al., 2011) distribution of species. Although distributional changes will be complex (Schiel et al., 2004), there is a general trend of poleward movement of species in the northeastern Pacific (Brodeur et al., 2003; Zacherl et al., 2003; Brodeur et al., 2005, 2006; Trudel et al., 2006; Wing, 2006; Orsi et al., 2007; Rogers-Bennett, 2007; Harding et al., 2011). An almost 300 km shift in the normal range of 20 species is expected from 2005 to 2055 (Cheung et al., work in progress). This is based on observations of the changing ranges of species both over decades and during warm/cool ENSO cycles (Orsi et al., 2007). For example, species rarely seen in coastal British Columbia were documented during the 1982–1983 El Niño (Fulton, 1985; Okey et al., 2012) and have been periodically observed more recently as well (Brodeur et al., 2006; Trudel et al., 2006; Wing, 2006). This resulted in temporary increases in biodiversity and was a function of climate variation, not climate change. However, as waters warm and the ecological transition zone marking the northerly range of many species not endemic to British Columbia moves northward, such occurrences may become more common.

Changing environmental conditions and proximity to an ecological transition zone may have shaped the development of a biota in the West Coast region that is relatively resilient and responsive to climate and oceanographic change. As climate change promotes an overlap of northern and southern transition zones, the associated increase in an already highly biodiverse region could help build ecological resilience (Okey et al., 2014). However, some species, including Pacific salmon, sardines, anchovies and Pacific hake (e.g., Robinson and Ware, 1999; Ware and Thomson, 2000; Wright et al., 2005), are extremely sensitive to changes in oceanographic conditions and may be negatively impacted. Variations in oceanic conditions may induce dramatic shifts in distribution and abundance of such short-lived species (i.e., 'boom and bust' cycles) but not of longer lived ones. This is because long-lived species that have little reproductive success during periods of environmental stress may survive to produce additional cohorts when conditions improve, whereas short-lived ones cannot.

Climate change is expected to become the dominant influence on marine conditions in the north Pacific during the next several decades (Overland and Wang, 2007). Long-term reorganizations of coastal species may include the separation in space or time of co-evolved species. For example, the timing of Cassin's and Rhinoceros auklet nestlings (a seabird) was historically aligned with the population peak of their prey, the copepod Neocalanus cristatus. As ocean temperature increased throughout the 1990s, the population peak of Neocalanus began to occur earlier in the year (Bertram, 2001). This caused a mismatch between the peak food demand of auklets and the population peak of a critical food source (Hipfner, 2008; Borstad et al., 2011). This example may foreshadow broader productivity-related ecological changes in Canada's Pacific because of the sensitivity of other key food sources and primary producers, such as plankton, to climate variability and change (Mackas et al., 1998; Bertram, 2001; Mackas et al., 2007; Batten and Mackas, 2009).

4 CLIMATE CHANGE EFFECTS ON SECTORS AND COMMUNITIES

Roughly four out of five British Columbians live in coastal cities, towns and villages (BC Stats, 2013a). Millions of people and billions of dollars in goods arrive each year at the airports, ports and ferry terminals that line the province's shores. The ocean is within metres of this critical infrastructure and, as sea level rises, so does the risk of flooding.

The variety of challenges climate change presents to this region's residents and industries is a product of their exposure to hazards (e.g., proximity to the ocean and elevation) and their capacity to adapt to the risks this presents (e.g., knowledge of the hazards and possessing the resources to respond).

There is a variety of potential climate change impacts on coastal communities and businesses, including sea-level rise, changes in storm frequency and intensity, and changing ecosystems. As sea level rises, the height of waves relative to the shoreline will increase due to deeper water and, with it, the destructive potential of higher waves during positive storm surges. New wave dynamics will also affect sediment resuspension and transport rates, and have the potential to reintroduce toxic materials, such as heavy metals, that have accumulated on the sea floor (Eggleton and Thomas, 2004; Kalnejais et al., 2007–2010; Roberts, 2012). Coastal settlements face increasing risk of land loss, infrastructure damage and impacts to the natural-resource and tourism industries (Klein and Nicholls, 1999; Craig-Smith et al., 2006). The general risks presented to different regions of the West Coast are summarized below:

Lower Mainland: The Lower Mainland has the largest population in the West Coast region, with nearly 61% of British Columbians and 75% of coastal residents (BC Stats, 2013b). It is also the fastest growing subregion in the province, with 1.6% annual growth projected for the next two decades (BC Stats, 2013b). Rapid development, urban densification and increased international trade through gateways located in low-lying areas exposed to sea-level rise and storm-surge flooding are a concern in this region. A 1 m rise in sea level could inundate more than 15 000 hectares of agricultural and 4 600 hectares of urban lands in the Lower Mainland (Yin, 2001). The estimated costs of raising the dikes to protect these exposed areas are in the order of $9.5 billion for Metro Vancouver (Delcan, 2012). As discussed in subsequent case studies (Section 4.2.2), Metro Vancouver and its member local governments are actively working to plan for adaptation to sea-level rise. Case studies in Section 4.3 examine two main economic hubs, Port Metro Vancouver and Vancouver International Airport, both of which have demonstrated awareness of the potential consequences of sea-level rise and are working with neighbouring municipalities to identify potential solutions.

Vancouver Island: On Vancouver Island, the Capital Regional District (CRD), comprising 13 local governments (including the provincial capital), is the province's second most populous region. The CRD does not face the same exposure to sea-level rise as Metro Vancouver given its slightly higher elevation and smaller population, but climate change nonetheless remains a concern. Sea-level rise will affect low-lying areas, including Victoria's Inner Harbour (an important source of tourism revenue) and Canadian Forces Base Esquimalt (the home of Canada's Pacific Fleet). Summer water shortages due to drought are the greatest near-term climate change–related concern in the CRD, which receives roughly half the annual precipitation of the Lower Mainland. The CRD is aware that climate change presents challenges and has begun adaptation planning (e.g., Capital Regional District, 2012).

Sea-level rise, storms and storm-surge flooding are a concern throughout Vancouver Island, with the effects of storm surges particularly pronounced where the coast is exposed to long stretches of open water. Potential disruptions to transportation networks, such as ferry services, from storms or damage to wharves is a concern for many of the small communities in this area.

North and Central Coast: Small communities along British Columbia's north and central coast have experienced significant social and economic disruption during the past two decades as a result of such non-climate factors as the decline of the regional fishing and forestry industries (e.g., Matthews, 2003; Young, 2006). Both the timber processing and fishing industries are now centralized and many jobs have moved to the Lower Mainland. For example, employment in the capture fishery is less than 25% of what it was 20 years ago (with estimated employment at 1400 in 2011; Stroomer and Wilson, 2013), and centralization of many of the remaining jobs has left relatively few fishers and fish processors in outlying areas.

In contrast to the decline of primary renewable industries, recent interest in energy development and shipping is promoting growth in some communities on BC's north coast, notably Kitimat and Prince Rupert. In these communities, climate change impacts of concern relate to increased storminess, which can potentially affect coastal export terminals and create hazardous conditions for shipping. Expansion of economic activity along the north coast is perhaps the most significant development since the last climate impacts and adaptation assessment for British Columbia (Walker and Sydneysmith, 2008).

Increased storminess is a concern for communities of the central coast. The one road connection to the region, Highway 20, can be washed out during major storms associated with atmospheric rivers, as demonstrated by the Bella Coola flood of September 2010. Flooding can damage property, infrastructure and habitat, and present a threat to human health and safety. Communities in this region are relatively isolated and access to other communities may be temporarily cut off during storms.

The remainder of this section begins by focusing on climate change implications for fisheries. It outlines how the sector is changing, and reviews potential challenges and strategies for adaptation. This discussion is followed by a review of potential community impacts, supported by a suite of case studies that illustrates the current state of adaptation in the region.

4.1 FISHERIES

> *Fishermen do not fish only from individual boats; it is fair to say that they also fish from communities. This is perhaps what most distinguishes the world of work in rural communities from the types of industrial and factory work found in larger centres… In agriculture and fishing communities, however the separation of work from community and family life makes no sense and is generally impossible… It is impossible to study the nature of work without being involved, ipso facto, in a study of community and family life. (Matthews, 1993)*

Fisheries have been an integral part of the social fabric of coastal communities in British Columbia for generations. Place-based fisheries are not just an economic sector but can also be an important part of social life. Fisheries, particularly salmon, are an important source of identity for both Aboriginal and non-Aboriginal British Columbians. For example, salmon play a particularly important role in First Nations communities by supporting cultural activities and providing food security.

Although the social importance of fish remains high, their economic contribution has been declining since the early 1990s (Box 1). Fisheries support approximately 14 000 jobs in British Columbia, down 30% from the nearly 21 000 jobs available 25 years ago (Stroomer and Wilson, 2013). The economic contribution of fisheries, measured by contribution to GDP (all sectors), decreased by 28.8% during the same period (Figure 7). The capture fishery led this decline, with smaller reductions in the real GDP output of the fish-processing and sport-fishing industries. The commercial-culture sector is the only fishery that has grown during this period.

The economic decline of the fishery sector is particularly severe compared to other goods-processing industries, which have increased by 41% over the past two decades (Figure 8). The BC economy grew by 72% during this time, led by the service-producing sector, which expanded by 85%.

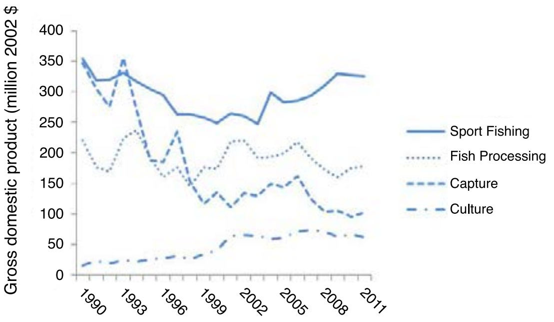

FIGURE 7: Real gross domestic product (GDP) by sector in British Columbia, 1990–2011 (Stroomer and Wilson, 2013).

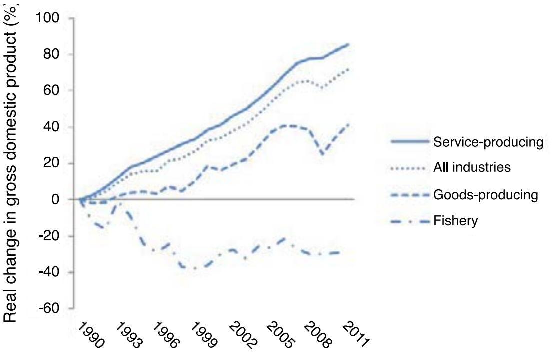

FIGURE 8: Real change in gross domestic product (GDP) by sector (Stroomer and Wilson, 2013).

4.1.1 CLIMATE IMPACTS

Changing marine conditions, including temperature, oxygen content and other biogeochemical properties, are currently affecting fisheries in British Columbia (Cheung et al., 2012). These changes are expected to continue and affect many species of fish (Section 3; Cheung et al., 2013). Changes in water temperature appear to have the strongest influence on fish. These well-known and quantifiable changes (Pauly, 2010) have affected species distribution, abundance, metabolism, growth and fecundity (reproductive success). For example, global-catch data from 1970 to 2006 show that commercial catches from Canada's West Coast region were increasingly dominated by warm-water species (Cheung et al., 2013). Such changes, after accounting for fishing effects and large-scale oceanographic variability, are strongly related to ocean warming.

Climate variability has historically played a strong role in Pacific fish stocks (e.g., Finney et al., 2002), primarily associated with natural climate oscillations, such as ENSO and PDO (*see* Chapter 2; Powell and Xu, 2011). However, as the climate shifts during the next century, changing conditions are likely to influence the distribution and abundance of marine species, with significant ecological implications (Beaugrand et al., 2002, 2008; Brierley and Kingsford, 2009; Cheung et al., 2009, 2010, 2013; Blanchard et al., 2012). For example, records show a more rapid decline of eulachon (smelt; *Thaleichthys pacificus*) in southern rivers along the Pacific coast relative to changes in populations encountered in rivers farther north (Moody and Pitcher, 2010), and there are reports of increasing occurrences of previously rare warm-water species, such as the Humboldt squid (*Dosidicus gigas*; Cosgrove, 2005; The Canadian Press, 2009) and increasing biomass of 'California' sardine (*Sardinops sagax*; Ishimura et al., 2012, 2013).

BOX 1
BC FISHERIES SECTOR

The British Columbia fisheries sector generated total revenue of $2.2 billion in 2011, representing a contribution of $667 million to provincial GDP and paying $338 million in wages (Stroomer and Wilson, 2013). Of this, recreational fishing accounted for 60% of employment and nearly half of the GDP generated by the sector (Table 1).

TABLE 1: BC fisheries industry overview, based on 2011 data (Stroomer and Wilson, 2013).

Fishery type	Labour force	Estimated contribution to GDP (million $)	% change in GDP, 1990–2011	Important species
Commercial capture	1 400	102.3	-70.5	Pacific salmon, herring, groundfish (e.g., halibut), shellfish (e.g., clams, crabs)
Commercial culture	1 700	61.9	298.1	Atlantic salmon, shellfish (clams, oysters, mussels)
Recreational	8 400	325.7	-8	Chinook, sockeye and coho salmon, halibut, trout
Seafood processing	2 400	177.5	-19.6	Pacific and Atlantic salmon, herring, groundfish
Total	13 900	667.4	-28.8	–

There is also evidence that salmon stocks are moving poleward in response to increasing ocean and river temperature (e.g., Moody and Pitcher, 2010). In southern British Columbia, a broad regional decline in sockeye populations has been recorded (DFO, 2011b; Irvine and Crawford, 2012, Peterman and Dorner, 2012), and there is reasonable confidence that sockeye production in the Fraser River is, and will continue to be, negatively affected by warming temperatures that impact marine and fresh-water populations at both adult and juvenile stages (MacDonald et al., 2000; Hyatt et al., 2003; Crossin et al., 2008; Hinch and Martins, 2011; McKinnell et al., 2011; Peterman and Dorner, 2011). Changes in water temperature can also affect the upriver migration and survival of salmon during the fresh-water stages of their life cycle (Welch et al., 1998; Cooke et al., 2004; Irvine and Fukuwaka, 2011; Rogers and Schindler, 2011; Selbie et al., 2011).

As glaciers decline, reduced river flow and related changes to water quality and temperature in glacier-fed watersheds may impact coho salmon, whose spawning patterns are linked to riverine discharge (Bryant, 2009). Warmer rivers can also delay sockeye entry into spawning grounds in the autumn and may trigger an earlier migration of riverine juveniles to the ocean, when coastal marine food resources are low (Bryant, 2009). Projections under different river-temperature scenarios have shown the potential for increasingly earlier timing of spawning runs (Reed et al., 2011).

While it is possible that southerly salmon populations may display some adaptation to warmer river temperatures, current evidence (e.g., the fate of California salmon populations; Katz et al., 2013) suggests an overall northward shift of relative population abundance and continued stress on stocks. Throughout the West Coast region, climate change represents a threat to small salmon stocks or those with unique habitat requirements (Bryant, 2009). Northern regions of the province will likely see neutral or positive outcomes for salmon (Peterman and Dorner, 2011), although this may last only a few decades.

4.1.2 IMPACTS ON FISHERY TYPES

COMMERCIAL CULTURE FISHERY

The commercial culture fishery is the fastest growing sector of the four BC fisheries examined here, increasing nearly 300% during the period 1990–2011, with most growth occurring between 1999 and 2007. Salmon represent the largest contribution to GDP in this sector, making up 86.7% of the total, while shellfish make up the remaining 13.3% (Stroomer and Wilson, 2013).[1]

Ocean acidification is a major challenge for economically important, heavily calcified shellfish like abalone (Crim et al., 2011), oysters (Kurihara et al., 2007), mussels (Melzner et al., 2011), clams (Ries et al., 2009) and sea urchins (Reuter et al., 2011). The wholesale value of the BC shellfish fishery (culture and capture) was $224.9 million in 2010 (BC Ministry of Agriculture, 2011). The effects of low-pH water have recently become important in BC aquaculture facilities, where entire

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[1] Salmon contributed $58.5 million to GDP, while shellfish contributed $9 million in 2011. However, the total contribution to this sector is only $61.9 million due to a loss of $5.9 million from other species.

cohorts of larvae have been lost when upwelling brings corrosive water up to the depth of a facility's intake pipes (R. Saunders, pers. com., 2014). The impact on the industry could run into the millions of dollars per year but is difficult to forecast due a scarcity of monitoring data.

Climate change may also impact the shellfish culture fishery via temperature-influenced zonation changes, forcing farmed organisms into deeper water. The upper limit of some predators, whose habitat is not likely to be affected, represents the limit of this downward vertical migration. As a result, the habitat range of shellfish gets squeezed. Potential impacts include difficulties in securing larvae and seedlings, whose health and productivity will be affected by both increasing acidity and disruption of temperatures (Huppert et al., 2009). Shellfish-culture fisheries may be able to adapt by moving operations farther north to colder waters, to avoid this temperature-predator squeeze.

COMMERCIAL CAPTURE FISHERY

The commercial capture sector has experienced a 70.5% decline in real GDP since 1990. The number of the jobs in the sector has decreased by 78.8% during the same period. Most of the decline in the capture fishery occurred during the 1990s (Figure 7), due in part to the reduction of many salmon subpopulations and a precautionary policy approach. The economic contribution of salmon declined by 82.5% over the period 1990–2011. In 1990, salmon accounted for 55.3% of the total value of the capture fishery in BC. By 2011, this proportion was reduced to 13.4% (Table 2).

Salmon no longer dominate this sector but are now one of several important catch species (Table 2) that also include halibut, geoducks and clams, and prawns and shrimp, demonstrating the adaptability of the sector. Groundfish (which include halibut, sablefish, hake and rockfish) are now the largest part of the BC capture fishery, making up 39% of the total value. The fastest growing species by economic importance is tuna, whose contribution to the sector was negligible 20 years ago but whose landed catch has since increased by nearly 35 times (Table 2).

It is important to note that groundfish catch alone is not likely to return the BC capture fishery to the values seen in the early 1990s. This is due to their longer reproductive lifecycles. For example, it takes halibut 2–3 times longer than salmon to reach sexual maturity (8–12 years). Halibut can also live 10 times as long as salmon, more than 50 years (Forsberg, 2013), and their reproductive potential increases with the size of the fish, meaning that the capture of large fish has a higher impact on replacement.

As the distribution of species along the west coast of North America shifts northward in response to changing climate, new species will become accessible and the availability of current species will change, presenting potential opportunities for fishers in British Columbia. It is also possible that such changes could create issues for the transboundary management of species that migrate between Canadian and United States waters. Collaborative management of emerging, economically important international stocks may become an important consideration for adaptation to changing fish distributions along the west coast of North America (Case Study 2).

TABLE 2: Changing composition of the capture fishery in British Columbia, 1990–2011 (Stroomer and Wilson, 2013). 'Proportion of total value' is the proportion (in %) that each species contributes to the real gross domestic product (GDP) of the wild-capture fishery.

Species	Proportion of total value, 2011 (%)	Proportion of total value, 1990 (%)	Change in real GDP from 1990 (%)
Salmon	13.4	55.3	-82.5
Halibut	13.2	4.4	116.1
Geoducks & clams	12.4	3.4	166.3
Prawns & shrimp	11.9	2.0	327.1
Crab	9.4	2.0	249.5
Tuna	8.3	0.2	3487.5
Sablefish	7.9	4.1	40.2
Rockfish	7.5	3.3	67.7
Other groundfish	5.5	3.9	1.1
Hake	4.8	2.7	28.9
Other (non-groundfish)	4.6	1.7	98.7
Herring	1.1	17.1	-95.3
Total	–	–	-27.6
All groundfish	39.0	18.4	53.3

CASE STUDY 2

TRANSBOUNDARY FISHERIES: THE CASE OF PACIFIC SARDINE

A country's exclusive right to manage and conserve fishery resources within its Exclusive Economic Zone (EEZ) was granted by the 1982 United Nations Convention on the Law of the Sea (UNCLOS). Although such rights legally rest with individual coastal countries, significant challenges can arise when it comes to the conservation and management of transboundary fish stocks (i.e., those whose distribution or migration extends over more than one country's EEZ (United Nations, 1982). In these cases, unilateral attempts to conserve and manage a transboundary fish stock usually lead to dissipation of the economic benefits and increasing risk of resource depletion (Miller et al., 2004; Munro, 2007). Non–co-operation management leads to what has been described as the "tragedy of free for all fishing" (Sumaila, 2013) because it results in inferior economic and ecological outcomes compared to co-operative solutions (Herrick et al., 2006; Bailey et al., 2010). However, there are a number of fisheries in the world where the co-operative conservation and management of a shared stock has been successfully negotiated among a limited number of countries (Clark, 1990; Sumaila, 1999).

The Pacific sardine (*Sardinops sagax*) is a transboundary fish stock that is presently fished exclusively by Canada, the United States and Mexico without a co-operative agreement (Ishimura et al., 2012). The Pacific sardine is a small pelagic schooling fish whose abundance and distribution within the California Current Ecosystem (CCE) are greatly influenced by climate variability (Hill et al., 2006) and are therefore sensitive to climate change. During the 20th century, the northern stock of this fish exhibited extreme fluctuations in its abundance and distribution, which have been attributed largely to climate variability inherent in the CCE (Norton and Mason, 2005; Herrick et al., 2006). By the 1970s, a cold regime shift in the CCE and overfishing resulted in the collapse of the stock, closure of the fishery and an 'endangered' species listing in Canada. In the 1980s, a warm regime shift, combined with conservation measures in California, saw the sardine population rebound to traditional levels and the fishery was reopened in the mid-1980s.

SPORT (RECREATIONAL) FISHERY

Sport fishing is the largest contributor to provincial GDP of all the fishery sectors, and is divided between saltwater (approximately 60%) and fresh-water (approximately 40%) fisheries. The number of tidal (saltwater) anglers has grown from roughly 145 000 in the year 2000 to 166 000 in 2010, while fresh-water angling held steady at approximately 236 000 during the same period (DFO, 2011a). The revenue derived by this sector is largely from the process of fishing, not the fish themselves. Because of this, there is overlap between the GDP contribution allocated to the sport fishery and the tourism industry. Therefore, any discussion about the potential impact of climate change on the sport fishery must extend beyond the availability and distribution of the fish themselves and include the accessibility and cost of sport-fishing opportunities.

Pacific salmon is a major source of income for the sport-fishing industry. Both local anglers and tourists pursue these fish, with the majority of fishing efforts occurring in the southern part of the province. It is possible that there would be a considerable impact on this sector if a northern distributional shift in salmon were to affect salmon numbers along the south coast. This is because of the reduced accessibility of north coast–based fishing charters and a potential reduction in expenditure on salmon-fishing gear in the southern part of the province.

FIRST NATIONS FISHERIES

Empirical data on First Nations fisheries is limited, outside of a small number of community studies (e.g., Weinstein and Morrell, 1994; Jacob et al., 2010), and little of the information is available in the public domain. Data are scarce on the species harvested and catch levels, the distribution and use of these catches, the needs and projected changing needs of communities, and the in-kind contribution of these fisheries to local livelihoods.

There are two principal categories of First Nations fisheries: subsistence (i.e., food or traditional) and commercial. The available data suggest that subsistence fisheries account for approximately 1% of the total marine catches in the Pacific region (Campbell et al., 2014). However, the true value of these fisheries far exceeds that which can be represented by measures such as contribution to GDP and revenue. As in the Arctic, subsistence fisheries serve to strengthen community resilience to environmental changes (e.g., Nuttall, 2001; Smit and Wandel, 2006) and are of great cultural importance, as they strengthen and build familial and social ties (Wenzel, 1991; Weinstein and Morrell, 1994; Berkes and Jolly, 2002; Lee, 2002).

Subsistence catches account for a significant proportion of in-kind income (up to one-third) for First Nations along North America's northwest coast (Vadeboncoeur and Chan, work in progress). The loss of access to traditional/wild foods has been related to both increased costs in healthcare due to dietary changes (typically the adoption of more nutritionally deficient diets) and the social-psychological stress resulting from relocation that can accompany the loss of an important part of livelihood (e.g., Callaway, 1995; Bjerregaard and Young, 1999; McGrath-Hanna et al., 2003; Arctic Climate Impact Assessment Secretariat, 2005).

The BC Assembly of First Nations has identified steps to maintain the viability of First Nations commercial fisheries, which often lack the spatial mobility of commercial fleets. The boats used for this fishery tend to be much smaller than those of large-scale commercial operations, thus limiting their range. Strategies for management of First Nations fisheries include, for example, ecosystem-based management of aquatic resources, habitat conservation and negotiations regarding fish allocation.

Both categories of First Nations fisheries, particularly those in southern BC, may be heavily impacted as distributions of abundance of species such as salmon, herring and eulachon shift northward. Changes to the timing and abundance of salmon runs can also present challenges to First Nations fishers, whose cultural activities and fish-preservation methods can be sensitive to such changes (Jacob et al., 2010). Ongoing negotiations between First Nations and the federal government may help address this problem by gradually shifting some fisheries from non-Aboriginal commercial operations to First Nations control (McRae and Pearse, 2004; BC Assembly of First Nations, 2007). Efforts are underway to understand First Nations vulnerability to climate change, and strategies for adaptation are being explored (Box 2).

4.2 COMMUNITY IMPACTS AND RESPONSES

Sea-level rise presents a long-term threat by increasing the risk of coastal flooding. However, it also increases the potential impact of storm-surge flooding (e.g., damage to nearshore infrastructure) because deeper nearshore water raises the height and energy of waves as they strike coastal structures. The extent of storm-surge flooding is related to wind speed and duration, length of fetch (how long waves can travel uninterrupted before breaking on the shore) and atmospheric pressure (*see* Chapter 2). Therefore, although sea-level rise itself presents risks, it is the combination of extreme high water levels associated with storms that has the greatest destructive potential.

The human and economic costs of extreme weather have been increasing in British Columbia over the past 40 years (Table 3; Public Safety Canada, 2013). This trend is expected to continue as the frequency and/or intensity of extreme weather events, such atmospheric rivers, increases.

4.2.1 THE DEVELOPED COAST

Recent efforts to prepare shorelines for the impacts of climate change have concentrated predominantly on sea-level rise. Other phenomena, such as atmospheric rivers, are associated with hazards such as overland flooding that can damage roads, dikes and private property, but an understanding of the severity and distribution of the associated risks is less developed. Therefore this section focuses primarily on sea-level rise.

BOX 2

CLIMATE CHANGE ADAPTATION IN FIRST NATIONS COASTAL COMMUNITIES IN BRITISH COLUMBIA

Climate change impacts are already affecting Aboriginal communities across Canada. The Climate Change Adaptation Program of Aboriginal Affairs and Northern Development Canada (AANDC) supports development of community-relevant information and tools for Aboriginal communities, governments and organizations to assess vulnerabilities to climate change and to develop adaptation plans. The program focuses on building capacity and addressing impacts related to coastal erosion, sea-level rise, drinking-water quality and quantity, extreme weather events, food security and emergency management.

Participants in the program include some BC First Nations coastal communities. For example, the Hartley Bay Band Council and Semiahmoo First Nation have carried out climate change vulnerability assessments and adaptation planning using a holistic approach that considers changes in both biophysical and socio-cultural environments. The Hartley Bay Band Council (Gitga'at territory, located on the northwest British Columbia coast) identified future changes in marine and terrestrial species as a key factor affecting the availability of traditional food. The Semiahmoo First Nation (southwestern British Colombia coast) assessed infrastructure vulnerability and the community's capacity to face these challenges. The assessment focused specifically on their water supply and distribution system, sewage system, road access and risk of flooding. The Semiahmoo First Nation has proposed specific adaptation actions that can address the key vulnerabilities identified.

TABLE 3: Forty years of extreme meteorological events in British Columbia (Public Safety Canada, 2013). Meteorological events include avalanches, cold events, droughts, floods, geomagnetic storms, heat events, storm surge, storms, severe thunderstorms, tornados, wildfires and winter storms.

Years	Average disaster events*per year	Average threshold events** per year	Normalized total cost per year of threshold events (millions of 2010 $)	Fatalities per year	Persons evacuated per year
1970–1980	1.3	0.6	29.9	2.5	345
1981–1990	1.5	0.5	14.3	4.6	64
1991–2000	2.5	1.1	42.7	1.5	2296
2001–2012	2.3	0.8	54	14	4899

* those recorded as 'meteorological disasters' in British Columbia by the Canadian Disaster Database
** those where damages exceeded $1 million 2010 dollars

There are several approaches to coastal protection for communities to consider and, given the relatively slow onset of sea-level rise, there is an opportunity for adaptation to be integrated into existing long-term infrastructure and community plans. Adaptation options are generally divided into five categories (*see* Chapter 3) that focus predominantly on options to deal with changes in the physical environment:

- protection (e.g., hard protection measures, such as sea dikes or seawalls, and soft protection measures, such as beach nourishment and revegetation of the nearshore)
- accommodation (e.g., elevated buildings, provision of alternative transportation routes)
- avoidance/retreat (e.g., removing high-risk structures and preventing new construction in flood-risk areas)
- no active intervention (e.g., a decision not to act following the review of available information)
- emergency preparedness (e.g., early-warning systems, evacuation preparedness, disaster response)

Hard protection measures are often expensive. However, there is evidence that the cost of adaptation will be less than the cost of inaction. For example, upgrading dikes in Metro Vancouver to protect the community from a 1 m rise in sea level is expected to cost about $9.5 billion (Delcan, 2012) but will protect an estimated $33 billion of assets exposed in the City of Vancouver alone (Hallegatte et al., 2013). In many cases, soft armouring measures may be less expensive than hard armouring, and may deliver similar protective benefits. For example, the City of West Vancouver undertook a pilot project of positioning boulders below the low-tide mark that is having success mitigating wave impacts (Section 4.2.2).

Accommodation responses seek to lower the risk of hazards while there is continued human use of infrastructure, lands and waters. Generally, accommodation allows for occasional, short-term impacts (e.g., impacts from storm events or seasonal flooding), and is an appropriate response when the practicality of protecting coastal assets is outweighed by the cost and/or the effectiveness would be limited to a relatively short period of time. Accommodation responses on the coast can utilize a range of actions, such as protection of local salt marshes or restricted use of designated areas.

Avoid-and-retreat measures include approaches such as designating hazard zones where construction is prohibited, and property buybacks in at-risk areas.

While the decision not to move forward with adaptation (do nothing) can be a valid option (e.g., when there is inadequate information or where the data do not indicate a hazard), it is recommended that such decisions be revisited as new information becomes available.

Each community will have unique needs and the range of appropriate measures must be considered on a case-by-case basis, considering both climatic and non-climatic factors. Proactive planning is important because the costs of adaptation can be reduced when adaptation is integrated with other ongoing operations, such as infrastructure maintenance schedules. For example, it is cheaper to move a sewer line when the pipes reach the end of their serviceable life than to remove or decommission it while it is still working well. Most adaptation plans will involve a number of initiatives from one or more of the categories of options, selected to respond to a range of local vulnerabilities and risks, which will change over time.

The type of coastal-protection infrastructure a community may select can have a marked impact on nearshore ecosystems. Hard-protection measures can cause coastal squeeze (*see* Chapter 3) and alter marine habitats as a result of changes to wave energy and local currents (e.g., Dugan et al., 2008; Dawson et al., 2009; Bulleri and Chapman, 2010). Alternatively, some forms of adaptation can facilitate ecological integrity, including efforts that reduce the use of hard armouring. The protection of existing natural coastal geomorphological features and habitats (Katsanevakis et al., 2011), and the application of principles for ecological conservation, can help reduce the impacts from both storm events and sea-level rise (e.g., Borsje et al., 2011).

Heavy precipitation events, such as those associated with atmospheric rivers, present challenges to adaptation planning in many coastal communities. This is because the structures built to reduce the impacts of coastal floods (e.g., dikes) could affect the functioning of storm-water management infrastructure. For example, dikes could present a problem for gravity-based drainage systems whose outflows have become submerged, allowing water to back up and accumulate on the landward side. The potential for more intense precipitation events may require increased pumping capacity, wider collection pipes and the relocation of storm-water discharge pipes.

A variety of guidance materials for adaptation to sea-level rise is available to local governments (e.g., Plan2Adapt, Climate Action Tool), who also have the authority to regulate exposure to flood risk through bylaws (BC Ministry of Environment, 2004). Alliances between local governments and other organizations, particularly universities and NGOs, have helped municipalities access scientific and technical expertise to better inform their adaptation planning.

Adaptation efforts can yield tangible benefits, such as increased wildlife habitat and enhanced biodiversity. The identification of benefits is important because these can be weighed against both the costs and the concerns of local residents who may have strong emotional attachments to particular features within their communities, as in the case of adaptation planning in Qualicum Beach (Section 4.2.2).

4.2.2 COMMUNITY CASE STUDIES OF ADAPTATION

This section highlights a range of approaches taken by communities across coastal BC (Figure 9) to adapt to climate change. The case studies are listed alphabetically and are followed by a summary of lessons learned.

FIGURE 9: Locations of community case studies.

CASE STUDY 3

CAPITAL REGIONAL DISTRICT: REGIONAL GOVERNMENT PLANNING FOR SEA-LEVEL RISE

(Nikki Elliot, Manager, Climate Action Program, Capital Regional District)

Located on the southern tip of Vancouver Island, the Capital Regional District (CRD) is the regional government for 13 municipalities and 3 electoral areas, including the provincial capital, Victoria. Storm-surge flooding is already a risk in the CRD (Figure 10). The potential for flooding of residential, commercial, institutional and municipal property and infrastructure in the CRD is expected to increase with sea-level rise. To reduce climate-related risks and vulnerabilities, the CRD Climate Action Program is leading a project that will better inform its member municipalities and other stakeholders on the implications of rising sea levels.

The CRD Climate Action Program was established through bylaw in 2008 and serves municipalities by acting as a resource, hub and facilitator on both climate change mitigation and adaptation issues. Working in partnership with public, private and nonprofit sectors, the Climate Action Program supports shifts in policy, planning, infrastructure and behaviour that are required to create a resilient and low-carbon region.

In late 2013, the CRD initiated a Coastal Sea-Level Rise Risk Assessment project as a first step to understanding the implications of sea-level rise within the capital region. The primary task of this project was to identify and map areas that are potentially vulnerable to sea-level rise. Mapping was based on the Province of British Columbia's *Coastal Floodplain Mapping—Guidelines and Specifications Report* (June 2011). Analysis focused on 24 areas that were selected because of the relatively high levels of expected future inundation and/or the location of key community assets. An assessment of the public and private assets in these areas was then undertaken to help local governments understand the potential economic risks of coastal flooding.

This project provided the CRD and its municipalities with:

- mapping showing potential inundation levels in each focus area;
- analysis of the expected depth of inundations;
- the area and percentage of key land uses in the focus areas;
- a summary of the public infrastructure and assets in the focus areas;
- the total value of private and public infrastructure and buildings in the focus areas;

FIGURE 10: December 2010 storm surge in the Capital Regional District. *Photo courtesy of the District of Saanich.*

- a description of the physical characteristics of the coastline in the focus areas; and
- three case studies on the potential disruption costs of sea-level rise (business area, residential area and transportation corridor).

This information provides municipalities with data at a spatial scale fine enough to allow the impacts of climate changes to be easily understood at the local level.

Based on the results of the Coastal Sea-Level Rise Risk Assessment project, the CRD Climate Action Program and their partners are engaged in a project to collect, evaluate and share potential planning, regulatory and structural approaches to address sea-level rise with municipal staff across the region.

CASE STUDY 4

CITY OF COURTENAY: CROSS-SCALE CO-ORDINATION FOR COASTAL-FLOOD MANAGEMENT

(Allan Gornal, Climate Action Analyst; Nancy Hofer, Environmental Planner; and Craig Armstrong, Professional Engineer, City of Courtenay)

The City of Courtenay, like other communities on the east coast of Vancouver Island, is addressing increased flood risk in the face of climate change. Major flooding of the Courtenay and Tsolum rivers in November 2009 and January 2010 disrupted transportation and emergency-response capacity, motivating the city to act (Figure 11).

FIGURE 11: Courtenay River flood, 2010. *Photo courtesy of the City of Courtenay.*

Adaptation planning began following the city's successful application to the BC Flood Protection Program. This funding was used for:

- updating of floodplain mapping;
- development of a hydraulic model to predict flood elevations for various environmental scenarios;
- investigation of flood-mitigation options (both hard and soft approaches);
- overall development of an integrated flood management study; and
- design and construction of flood protection works.

Two climate change impact scenarios were considered. The first assumed a 1 m sea-level rise by 2100, following the Guidelines for Management of Coastal Flood Hazard Land Use (Arlington Group et al., 2013) and a 15% increase in peak river flows by 2100, based on the flood hazard guidelines of the BC Association of Professional Engineers and Geoscientists (Association of Professional Engineers and Geoscientists of British Columbia, 2012). The second scenario considered changes between 2100 and 2200, and included an additional 1 m increase in sea level and an additional 15% increase in peak river flows.

Analysis of these scenarios informed an integrated flood management study (City of Courtenay, 2014), which presented a series of flood-mitigation options. The study included options for both hard armouring (e.g., dikes and floodwalls), improved infrastructure (e.g., overland systems to disperse flood waters and increase retention areas) and accommodations and avoid/retreat approaches, such as rezoning, amendment of flood-control levels to account for the risks presented by rising sea level and limiting development in areas identified as being at risk. Approaches to planning and flood management will likely involve a combination of these options, following consultation with the community.

Ongoing work includes the development of the K'ómoks Estuary Management Plan, which will provide a policy framework for the multiple jurisdictions bordering the estuary (including the K'ómoks First Nation, Comox Valley Regional District, City of Courtenay, Town of Comox, Fisheries and Oceans Canada and other authorities). The objectives of the plan are to establish short- and long-term guidelines for human activities in the estuary; to reduce or prevent negative impacts of human development and/or activities on water quality and aquatic and terrestrial ecosystems; and to restore degraded habitat and protect existing habitat. The plan provides policy guidance for numerous activities within the estuary, including the protection of cultural heritage and water quality; wildlife management; the use of recreation and greenways; and guidelines for urban development, navigation and dredging, log storage and handling, agriculture and aquaculture. The plan is an important component of an integrated flood-management strategy that will highlight the potential effects of land-use change for both the community and local ecosystems, and will facilitate the cross-scale co-ordination needed for the successful management of a floodplain that crosses local-government boundaries.

Elements of the plan that help to address the impacts of climate change include:

- co-ordinated floodplain mapping and management bylaws amongst all local-government jurisdictions that account for potential sea-level changes;
- consistent setbacks in zoning bylaws; and
- consistent Development Permit Area guidelines regarding site and building design relative to setbacks and buffers.

CASE STUDY 5

CORPORATION OF DELTA: DEALING WITH UNCERTAINTY

(Angela Danyluk, Senior Environmental Officer, Corporation of Delta)

Delta is a low-lying coastal community of approximately 100 000 people located on the Fraser River estuary (Figure 12). This ecologically important area forms part of the Pacific Flyway, a conservation area that provides habitat for millions of overwintering songbirds, waterfowl and raptors. It consists of an expansive intertidal zone, comprising wetlands, eelgrass meadows and farmlands, that supports marine invertebrates and coastal salmon populations (Hill et al., 2013); and Burns Bog, a protected area containing a rare raised peat bog of high ecological and cultural significance.

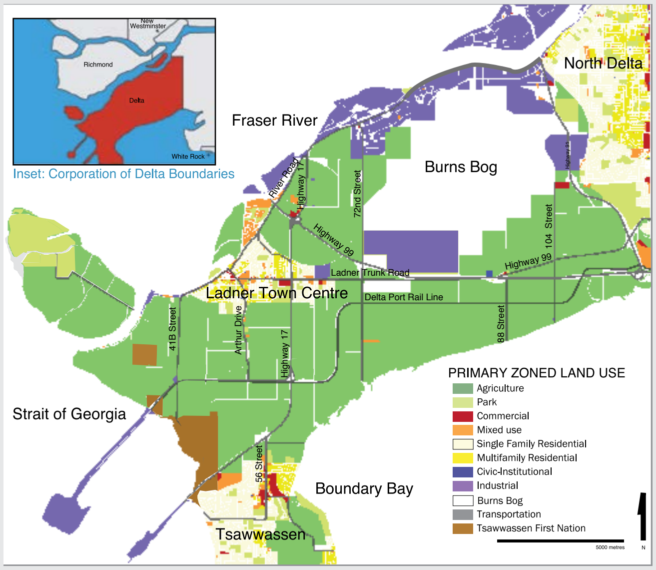

FIGURE 12: Land-use map of the Corporation of Delta created by the Collaborative for Advanced Landscape Planning (CALP) at the University of British Columbia. Image credit for map: G. Canete. Image source for inset map: http://en.wikipedia.org/wiki/File:GVRD_Delta.svg.

The aquatic ecosystems surrounding this community may be somewhat resilient to climate change because important species such as eelgrass will likely shift landward as sea-level rises. Local marshlands and mud flats could be eroded and decrease in area, but new accretion processes may offset these changes (Hill et al., 2013). Overland flooding presents a major hazard to the human community. Roughly 35 000 residents are considered acutely vulnerable to flooding, as are approximately 9 400 hectares of farmland (BC Agriculture and Food, 2013b) and major infrastructure installations, including marine terminals (Roberts Bank coal and container terminals), the rail lines serving these terminals and BC Ferries' busiest terminal, Tsawwassen.

Two major causeways that extend over Roberts Bank, a large undersea bank that provides habitat for salmon during their early life stages, fall within the jurisdiction of the Corporation of Delta. The first causeway supports a rail link to Canada's largest coal export hub—the Westshore Terminal. The second causeway connects to the Tsawwassen Terminal of BC Ferries. The ferry terminal handles roughly 8 million passenger trips per year on routes to Victoria, Nanaimo and the Gulf Islands. These causeways and their associated transportation facilities, along with a network of protective dikes and the nearshore built environment, represent the existing infrastructure in Delta most directly exposed to threats from sea-level rise and storm events. The Tsawwassen Commons, a major commercial and residential development project located between the two causeways on lands owned by the Tsawwassen First Nation, is under construction and will also be at risk. Waves will become more powerful as sea-level rise causes deeper water over Roberts Bank, putting greater stress on coastal infrastructure and ecosystems. Planning for these impacts has been a collaborative process, with local stakeholders involved throughout (Hill et al., 2013).

Following work to identify potential physical hazards of climate change (Hill et al., 2013), the Corporation of Delta partnered with the Collaborative for Advanced Landscape Planning (CALP) at the University of British Columbia to facilitate engagement with the public. Using local climate change projections and current land-use data, CALP mapped anticipated physical changes (Figure 13) and produced visualizations to assist in the identification of adaptation options, based on a range of future scenarios (Figure 14). Because the visualizations used local data, they clearly conveyed the range of social, environmental and economic impacts facing the community and its infrastructure. Sharing results with staff and citizens stimulated discussion about community values, opportunities and solutions in response to the impacts of climate change, thereby increasing awareness and capacity.

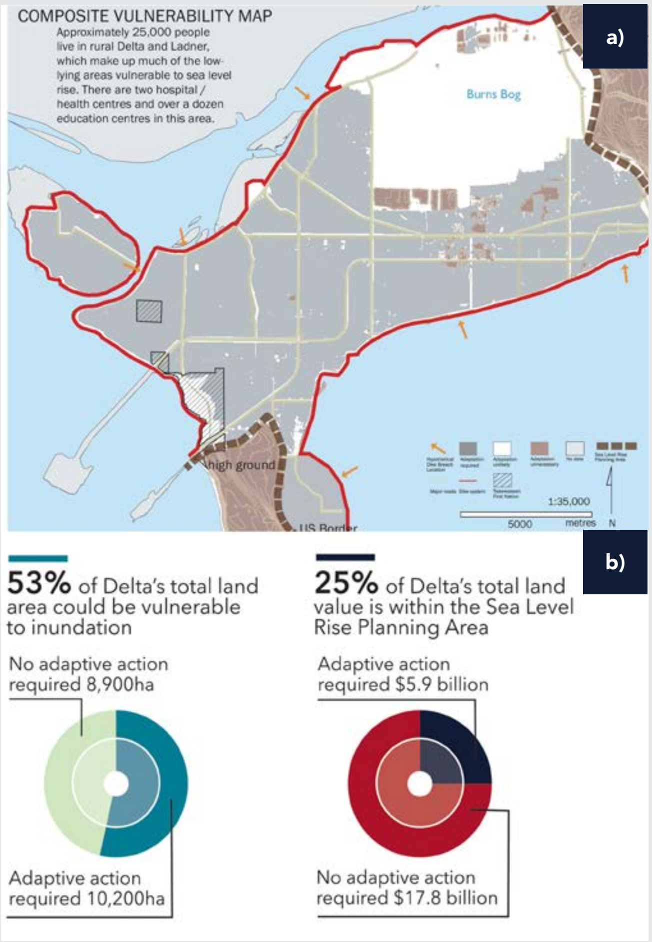

FIGURE 13: Composite vulnerability map in the Corporation of Delta (Barron et al., 2012).

Delta's improved understanding of the potential effects of a changing climate contributed to its selection as one of three agricultural climate change adaptation pilot projects (BC Agriculture and Food, 2013a). In partnership with farmers, the provincial government and the federal government, Delta is now working to implement recommended actions. Corporation staff are also developing an adaptation strategy (through the Building Adaptive & Resilient Communities [BARC] Program of ICLEI Canada) to protect the community from flood hazards, promote agricultural resilience, enhance natural-area and urban-forest resilience, and ensure the health and safety of residents.

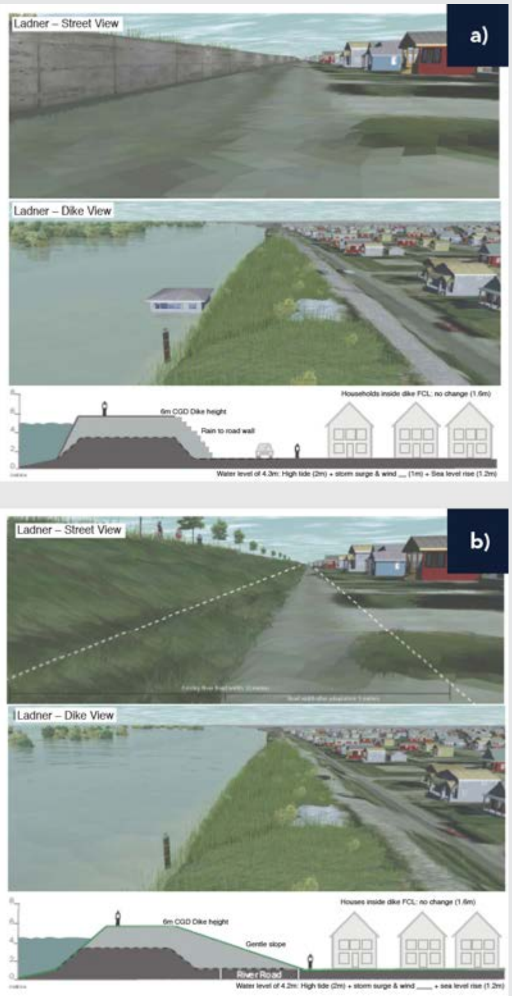

FIGURE 14: Visual models of potential adaptation options. Images are of Ladner (part of the Corporation of Delta) with a larger dike and berm in 2100 with 1.2 m of sea-level rise. The dike has been built up accordingly, and the images show two design options: **a)** a steep concrete-reinforced wall that would maintain the current right-of-way for River Road; and **b)** a conventional design that would take up half of one of the main roads. Source: Corporation of Delta. Created by Collaborative for Advanced Landscape Planning (CALP), University of British Columbia.

CASE STUDY 6

TOWN OF GIBSONS: ADAPTATION PLANNING IN COLLABORATION WITH A UNIVERSITY

(Michael Epp, [former] Director of Planning, Town of Gibsons; [currently] Planner, City of North Vancouver)

Residents and leaders of Gibsons, a town of 4400 people on BC's Sunshine Coast (Figure 15), have a history of proactive action to address environmental issues. However, when the town initiated community conversations about climate change in 2009, it was considered secondary to other concerns, such as municipal finances, infrastructure and development. The impact of recent extreme weather events has since changed this impression. Severe drought in the summer of 2012 threatened water supplies and an unusually high king tide (the highest tides of the year, which occur near both the summer and winter solstices) in December of the same year sparked recognition that sea-level rise is an issue of immediate concern. The town has determined that, over the next several decades, new construction will need to consider future sea levels and that municipal infrastructure must be relocated where appropriate.

In 2011, the Town of Gibsons became a community partner in a University Community Research Alliance project that aimed to advance adaptation planning for climate change in coastal communities. As a result of this partnership, the town now has a model of the potential extent of flooding associated with sea-level rise (Figure 16). Existing land, property and LiDAR data were combined with estimates of sea-level rise by 2100 to provide a model of the potential extent of coastal flooding and the cost of damaged assets. Estimates of the financial impacts of flooding associated with sea-level rise and storm surges start at $20 million.

FIGURE 15: Gibsons harbor from the air. *Photo courtesy of the Town of Gibsons.*

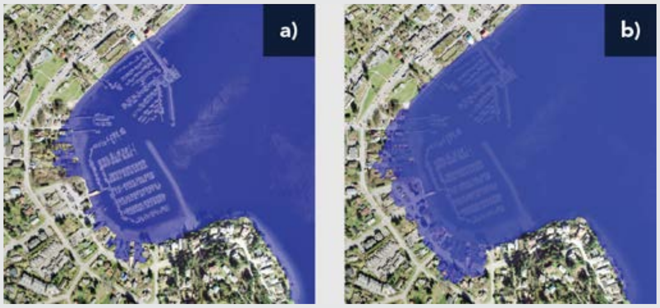

FIGURE 16: Projected future water levels in Gibsons Harbour under conditions of **a)** 1 m of sea-level rise, and **b)** 1 m of sea-level rise (dark blue) and a 1.1 m storm surge (light blue). The town's main sewer line is submerged in both models, whereas three blocks of high-value properties, a gas line and marina facilities are exposed to storm-surge impacts (N. Vadeboncoeur, unpublished data, *base image from* Google, 2015).

As part of their 2013 strategic planning process, the town decided to undertake, over the next several years, a systematic assessment of the shoreline. Data collected will build on the modelling provided by the town's research partners and assist analyses of adaptation options (e.g., where armouring might be required, where slopes are unstable and where natural plantings might assist in reducing risk). A comprehensive review of the Official Community Plan (OCP), which guides future development of the town, is underway, and has provided an opportunity for a broader integration of specific climate adaptation policies into community planning. This allows adaptation measures to be considered along with life-cycle and cost-benefit analyses of infrastructure that form part of the OCP review.

CASE STUDY 7

QUALICUM BEACH: A LAND-USE APPROACH TO ADAPTATION

(Luke Sales, Director of Planning, Town of Qualicum Beach)

The waterfront plays an important role in the economy and social identity of the Town of Qualicum Beach, located on the eastern shore of Vancouver Island. Maintaining the character of the town waterfront is a top priority. Historically, the town has taken a reactive approach to foreshore management of storm impacts, including ecosystem degradation, beach loss, waterfront flooding and damage to the sea wall (Figure 17). However, Qualicum Beach is now in the planning phase of a comprehensive Waterfront Master Plan that will include planning for adaptation to sea-level rise. The work will be undertaken in two phases,

FIGURE 17: Qualicum Beach waterfront walkway during a strong winter storm in 2009. *Photo courtesy of S. Tanner.*

the first aimed at understanding the technical and scientific dimensions of change, and the second focused on planning to manage the change.

The first phase, completed in late 2014, involved an assessment of local meteorological, oceanographic and geomorphological conditions, and the dynamic processes that control the nature of the town's waterfront. This analysis highlighted the specific impacts that waves, storms and sediment-transport rates have on the shoreline, and that different areas of the waterfront behave differently.
For example, there are some areas where sediment travels aggressively, eroding quickly in places and accumulating in others. In contrast, the central waterfront (where parks and many services are concentrated) has very little erosion. The results of the first analysis will inform the second phase of the project, which will help refine planning approaches to provide for a sustainable waterfront that is resilient to climate change impacts. For example, the town is now considering 'soft' approaches, such as gradually building up their central waterfront over time as a potential adaptation measure.

The second phase of the project will focus on public consultation and a detailed examination of opportunities for shoreline restoration, land use, ecological protection, tourism, pedestrian and cycling infrastructure, parking, design standards, public access and other community priorities. Cross-disciplinary approaches to coastal planning will draw upon experts in the fields of geomorphology, urban design and coastal biology to develop a comprehensive plan for community sustainability.

The project goals include:

- improving the town residents' understanding of local foreshore ecology and natural processes;
- identifying strategies for managing a changing foreshore interface and minimizing cumulative impacts on the coastal environment;
- developing a comprehensive waterfront master plan that identifies strategies and actions required to adapt to sea-level rise while maintaining amenities; and
- developing guidelines for shoreline works that can be followed by private property owners as part of an integrated approach to shoreline management.

While the project presents an opportunity for the community to improve the waterfront for future generations, the process will likely be emotional and some community members perceive it as threatening to the owners of waterfront homes and businesses. During the second phase, the town will initiate a dialogue about these concerns and evaluate feedback on the range of options from the community.

CASE STUDY 8

CITY OF VANCOUVER: PREPARING A HIGH-DENSITY CITY FOR SEA-LEVEL RISE

(Tamsin Mills, (former) Senior Sustainability Planner, City of Vancouver)

The City of Vancouver has, for more than 20 years, been committed to addressing climate change (City of Vancouver, 1990). Vancouver faces considerable risks from climate change, and was recently identified as the 11th city most at risk to sea-level rise in the world, based on the total value of exposed assets (Hallegatte et al., 2013). With many high-density areas and other uses adjacent to the ocean (Figure 18), options to respond to the effects of climate change are limited. Adaptation measures are likely to involve a combination of protection measures coupled with urban-planning instruments, based on a sophisticated

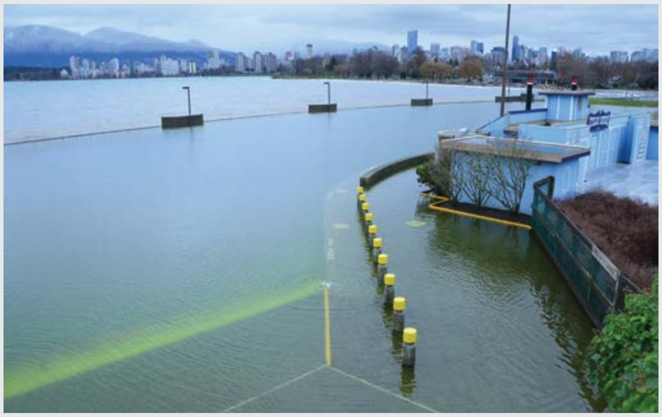

FIGURE 18: King tide of December 17, 2012 with little accompanying wave action caused localized inundation in the City of Vancouver, including flooding of the Kitsilano Pool. *Photo courtesy of the City of Vancouver.*

understanding of the spatial distribution of potential floods.

In 2007, largely in response to findings of the IPCC Fourth Assessment Report, Vancouver City Council passed a motion to initiate an adaptation-planning process. First steps included a risk analysis to identify priority areas for adaptation, leading to a more comprehensive climate action plan that was adopted unanimously by Council in July 2012. The primary actions identified in the action plan are now being addressed and the city is, at the time of writing, acquiring the data required for implementation of the plan. For example, LiDAR imagery was collected in early 2013 to assist with mapping of the vegetation canopy and coastal flooding. The coastal-flooding maps have since been integrated into a model showing the area, depth and flow rate of overland flooding.

In 2013, Vancouver became the first city in British Columbia to adopt formal consideration of 1 m of sea-level rise in development and planning requirements. The city is currently weighing a number of other development-planning options. Because of its location in the centre of coastal Metro Vancouver, adaptation in Vancouver is a particularly collaborative process. For example, the city is working with the Port of Metro Vancouver, the Fraser Basin Council (a nongovernment organization) and the neighbouring City of Burnaby to develop a strategy for managing sea-level rise in shared floodplains that would include improved coastal armouring.

CASE STUDY 9

CITY OF WEST VANCOUVER: AN EXAMPLE OF ACCOMMODATION OF WAVE IMPACTS

(David Youngson, Director of Planning, City of West Vancouver)

The growth of West Vancouver, a community of more than 43 000 people, has resulted in urbanization of the watershed and waterfront, producing a hardening of the shoreline and channelization of watercourses. The resulting disruption to sedimentation processes has increased sediment transport and reduced rates of deposition. For example, it is not uncommon for hundreds of cubic metres of sediment to be eroded from local shorelines during a single rain event. Such erosion results in deeper nearshore waters, exposing West Vancouver's infrastructure, near-shore habitat and beaches to increased wave energy (Figure 19). The city is working to achieve a stable shoreline that takes into account projected sea-level rise, protects uplands and promotes marine life.

In 2005, the West Vancouver Engineering Advisory Committee developed a Long-Term Shoreline Planning Framework. Later that year, the West Vancouver Shoreline Preservation Society was created. These organizations together acted as a catalyst for channelling more than 30 years of research on the shoreline into a process for restoring the district's beaches. The result, the 2012 Shoreline Protection Plan (SPP), is a living document designed to respond to the ecological and social needs for the shoreline, to direct available resources and to take advantage of opportunities for the greatest benefit of the foreshore.

FIGURE 19: Wave damage to the West Vancouver seawall during a storm. *Photo courtesy of the West Vancouver Shoreline Preservation Society.*

The first SPP action was the creation of nine municipally funded, shoreline-protection pilot projects, located between the Capilano Groyne and Navvy Jack Point. These projects varied in scale, cost and focus, but shared the key goal of improving shoreline protection. Each project involved an array of coastal-engineering and habitat-enhancement strategies to restore sites to a more natural state and to provide self-sustaining, soft-armouring measures for the shoreline. For example, a pilot project involving the addition of subtidal boulders (located just below the low-tide mark) has reduced erosion and sediment transport while improving habitat (Figure 20).

Benefits of the work undertaken to date include:

- naturalization of the shoreline through removal of more than 200 m of concrete sea walls;
- increased biodiversity of riparian, intertidal and subtidal zones;
- improved creek access for salmon;
- re-establishment of functioning surf smelt habitat;

FIGURE 20: Submerged boulders provide habitat for plants and echinoderms while enhancing spawning grounds for smelt. *Photo courtesy of the West Vancouver Shoreline Preservation Society.*

- increased public access through the installation of bridges and nearshore pathways; and
- improved shoreline stability and high beach habitat through the accumulation of large woody debris and organic material.

Five privately sponsored initiatives have subsequently built upon the pilot projects and demonstrate the potential for sustainable management of the entire 30 km of West Vancouver's privately and publicly owned waterfront. The private initiatives have resulted in more than $3 million of shoreline restoration work being undertaken between Dundarave and Horseshoe Bay. This has helped to retain sediment (decreasing water depth and wave power) and to reduce the impact of waves on the shoreline.

4.2.3 LESSONS LEARNED

A common theme among these case studies is that collaborative efforts with other organizations or with private partners enabled local governments to move forward on adaptation planning and implementation. In all cases, external partners helped support adaptation and, in the case of the Capital Region District, they also helped support member local governments in planning for change. In several studies, data highlighting the timeline for projected impacts have allowed adaptation to be considered along with existing cost-benefit analyses, such as for infrastructure maintenance schedules, and permitted adaptation to be 'mainstreamed' into existing policy processes, such as official community plans.

The adaptation measures adopted by each municipality varied based on its specific needs and the projected effects of climate change on their communities. As demonstrated in the West Vancouver Case Study, municipalities need not rely solely on dikes for coastal protection. Sub–sea-surface structures located within tidal areas can help mitigate erosion by reducing wave energy reaching the shore and by enriching habitat. In some cases, coastal protection on its own may be insufficient for addressing storm impacts accentuated by sea-level rise and, as in the case of Vancouver, changes to urban planning and development regulations, such as elevated Flood Construction Levels, may be needed.

Adaptation measures intended to build community resilience to climate change can have positive effects on local assets and local society, as well as on local ecosystems. Adaptation can assist with maintaining beaches, protecting existing habitat and creating new habitat. However, implementation of some adaptation measures, such as restrictive zoning and coastal setbacks, can present challenges for both communities and individuals. Because the effects of coastal adaptation to climate change can be far-reaching, public consultation is an important part of adaptation planning and ensuring that changes are implemented in a timely, controlled manner that is respectful of the needs of stakeholders. When adaptation measures are applied in response to local disasters (e.g., a major storm event), the often sudden alterations to local land use can be difficult for affected members of a community to accept.

Communities along the coast have access to a variety of sources of information on the effects of climate change on coastal areas, and a range of potential partners with whom they can work to develop effective adaptation responses (Box 3). To date, responses are aimed overwhelmingly at reducing the increased risk of coastal flooding due to sea-level rise and storm surges. As municipal awareness of the need for climate adaptation continues to build, partnerships between local governments and external partners can assist in identifying and managing other climate risks to coastal communities.

4.3 TRANSPORTATION INFRASTRUCTURE

As Canada's 'Gateway to the Pacific', British Columbia features several facilities of national importance, such as Vancouver International Airport (YVR) and major marine transshipment ports (e.g., Port Metro Vancouver, Kitimat Port and Prince Rupert Port). Coastal areas are also home to regionally important economic and social links, including ferry services to small communities, a major road link to small communities along the north coast (Highway 16) and an array of smaller land- and water-based airports. This section reviews potential risks this infrastructure may face as a result of climate change.

BOX 3
ADDITIONAL RESOURCES FOR COMMUNITIES

Adapting to Climate Change: An Introduction for Canadian Municipalities:
https://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/municipalities/10079

Agricultural Adaptation in Delta:
http://www.delta.ca/environment-sustainability/climate-action/adapting-to-change

BC Agriculture and Food Climate Action Initiative:
http://www.bcagclimateaction.ca/

BC Real Estate Association (BCREA) Flood Protection:
www.bcrea.bc.ca/government-relations/flood-protection

BC Sea-level Rise Adaptation Primer:
http://www.civicinfo.bc.ca/Library/Reports_and_Briefs/Sea_Level_Rise_Adaptation--Climate%20Action%20Secretariat%20--2013.pdf

Collaborative for Advanced Landscape Planning (CALP):
http://calp.forestry.ubc.ca/

ICLEI Canada Adaptation Framework:
http://www.icleicanada.org/programs/adaptation/barc

Joint Program Committee for Integrated Flood Hazard Management:
www.fraserbasin.bc.ca/water_flood_projects.html

Pacific Institute for Climate Solutions (PICS):
http://pics.uvic.ca/

Pacific Climate Impacts Consortium Plan2Adapt Tool:
http://www.pacificclimate.org/analysis-tools/plan2adapt

Stewardship Centre of BC Green Shores Program (Sea-level Rise Accommodation):
www.stewardshipcentrebc.ca/greenshores

4.3.1 AIRPORTS

Of the 78 airports in British Columbia that have International Aviation Transportation Association codes, five are exposed to increasing risk of flooding as a result of sea-level rise and storm surges because of their low elevations (<5 m above sea level). These are Vancouver International Airport, three regional airports (Boundary Bay, Pitt Meadows and Masset) and one recreational airstrip (Courtenay). Vancouver International plays a major role in the regional economy (Case Study 10), while the other airports contribute substantially to their local economies. Throughout British Columbia, water-based airports provide an important link for many rural coastal communities and complement other transportation modes in major cities such as Vancouver and Victoria.

CASE STUDY 10
VANCOUVER AIRPORT AUTHORITY

Vancouver International Airport is the largest air transportation hub on Canada's West Coast and the second busiest airport in Canada, moving approximately 17 million passengers each year through nearly 300 000 aircraft movements. Airport operations support approximately 24 000 jobs in Metro Vancouver, generate $5.3 billion in total gross domestic product and contribute $11.7 billion in total economic output. The airport itself is located on Sea Island, which is on the western boundary of Metro Vancouver between the cities of Vancouver and Richmond. Elevations of parts of the airport are near current sea level and part of the Fraser River floodplain (Figure 21). As a result, the airport is exposed to hazards associated with sea-level rise, storm surge and heavy-precipitation events. Most of the built environment, such as taxiways, runways, roads and buildings, is located above current flood levels, but much of the undeveloped land, such as the grass infields between taxiways and runways, is low lying and subject to flooding during major rainstorm events.

The Vancouver Airport Authority manages flood-control dikes on Sea Island and is working to gradually increase the height of these dikes. Both the Authority and the City of Richmond have authority over sections of the Sea Island dike system and, through a strong working relationship, keep one another abreast of their dike maintenance plans so that the flood risk for Sea Island can be collaboratively managed. There is an existing program to increase the height of the original dikes (constructed 1930–1940), now under the control of the Airport Authority, to a crest elevation of 4 m to better handle future ocean conditions. The Airport Authority recognizes that a 4 m dike elevation will provide insufficient protection for the year 2100 and is undertaking a systematic retrofitting initiative to both help spread costs over time and be able to respond to changing sea-level projections. Based on current sea-level rise projections to the year 2100, the potential flood level for the Vancouver Airport is 4.9 m and the estimated required

FIGURE 21: Vancouver International Airport from the air.
Photo courtesy of the Vancouver Airport Authority.

crest level is 7.9 m (Delcan, 2012), indicating that major upgrades to the Sea Island dike system will be needed. It is also noted that, while it will be relatively easy to make these changes for much of the Sea Island dike system, there are some locations where current land-use will make dike upgrades difficult.

In addition to maintaining a dike network, the Airport Authority also maintains a storm-water management system that drains accumulated water into the Fraser River by gravity at low tide, with pumps available to assist with drainage during the remainder of the tidal cycle. As sea level rises, the potential for gravity drainage will decrease, necessitating additional costs for pumping infrastructure and maintenance.

4.3.2 PORTS AND NEAR-PORT INFRASTRUCTURE

British Columbia supports major goods-shipping terminals and is home to a growing energy-export industry. Its approximately 135 public and private ports provide a strategically important trade link to the international market, facilitating roughly 95% of international trade in the province. The port system has helped to diversify BC's and Canada's export markets in response to global economic changes. For example, the proportion of BC's exports going to the United States declined from approximately 70% in 2001 to 44% in 2012 (BC Stats, 2013c).

Current major infrastructure installations include, for example, the Trans-Mountain Pipeline, Westridge Marine and Burnaby terminals, and the coal-export terminals on Roberts Bank (Port Metro Vancouver) and at Prince Rupert (Ridley Terminals). Several liquefied natural gas export terminals are under consideration for the Prince Rupert and Kitimat areas. Currently, existing and planned energy-related infrastructure along the BC coast is valued in excess of $100 billion.

The two main ports are the Port of Metro Vancouver and the Port of Kitimat. Each faces challenges as a result of climate change. Although sea-level rise alone is unlikely to present a direct challenge to infrastructure in British Columbia's two major ports by the year 2100, associated impacts, such as changing sediment-transport rates around port infrastructure, could factor into operational planning (e.g., Hill et al., 2013). The Port of Metro Vancouver (Case Study 11) is already working with bordering communities to identify vulnerabilities and plan for adaptation (e.g., a review of dike vulnerability along the border of the City of Vancouver). However, the many jurisdictions with which the port must interact (e.g., 17 sea-dike authorities responsible for maintenance and upgrading of protective works) complicate the potential for, and timing of, adaptation.

CASE STUDY 11

PORT OF METRO VANCOUVER

The Port of Metro Vancouver is a central part of the BC economy and delivers considerable additional benefits at the national scale (Tables 4 and 5). It links more than 160 countries through its 28 major marine terminals, moving 130 million tonnes of cargo each year. It is the busiest port in Canada, fourth busiest in North America and the most diversified on the continent, with services accommodating a range of needs from bulk and breakbulk[2] to cruise ships. The port lands include more than 600 km of ocean and river shoreline that borders with 16 municipalities and one treaty First Nation, and intersects with a further seven traditional territories.

The Port of Metro Vancouver considers sea-level rise on a project-by-project basis and is satisfied, based on current sea-level rise estimates, that its terminals are sufficiently elevated to avoid inundation. However, there has been no comprehensive characterization to date of the exposure of port facilities to sea-level rise. Land-based port infrastructure may be vulnerable if dikes of the municipalities bordering port facilities are not updated to an adequate standard. While there has been significant progress on adaptation in the City of Vancouver and Corporation of Delta (Section 4.2.2), a comprehensive assessment of risk is not possible until all 17 neighbouring dike authorities have released more detailed plans for adaptation. This is because of both the need for a co-ordinated flood-protection strategy and the effect that hard-armouring flood-prevention measures can have on sediment-transportation processes.

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[2] Breakbulk cargo is commodity cargo that must be loaded individually into a ship's cargo hold. The goods can be packaged in bags, cases, crates, drums of barrels, or kept together by baling and placed onto pallets. Typical breakbulk commodities include paper, lumber, steel and machinery (Port Metro Vancouver, 2013).

TABLE 4: Economic benefits of Port Metro Vancouver (Intervistas Consulting Inc., 2009).

Jurisdiction	Contribution to GDP (billion $, estimated)	Total economic output (billion $, estimated)	Total wages (billion $, estimated)	Number of jobs
British Columbia (direct impact)	4.1	9.8	2.2	47 700
British Columbia (indirect and induced effects)	3.8	7.3	2.6	58 400
Canada (excluding BC)	2.6	4.9	1.3	23 400
Canada (total)	10.5	22	6.1	129 500

TABLE 5: Tax revenue from Port Metro Vancouver (Intervistas Consulting Inc., 2009).

Jurisdiction	Annual tax revenue (million $, estimated)
Federal	648
Provincial	417
Municipal	157
Total	1 222

Climate change may have an impact on operations at other smaller ports throughout the province. Increased frequency or magnitude of storms (*see* Chapter 2) could impact shipping, but there is insufficient information to draw conclusions about the individual or collective vulnerability of small ports to climate change.

4.3.3 HIGHWAYS

Although most coastal highways in British Columbia are located at elevations above projected increases in sea level and storm-surge flooding, available elevation and LiDAR data suggest that some sections of provincial highways could be vulnerable (Figure 22; BC Ministry of Transportation and Infrastructure and Nodelcorp Consulting Inc., 2011). The impacts of storm waves could present major challenges for some road sections, but assessing these vulnerabilities will require site-specific assessments. Flooding of highways by storm surges and storm waves can result in a sudden and temporary loss of what is often the only high-volume, rapid connection between coastal communities (Case Study 12). Some highways located near sea level have been protected by a series of dikes (e.g., in the Corporation of Delta; Section 4.2.2).

FIGURE 22: Areas of provincial coastal highways identified as being at risk from sea-level rise (*modified* from D. Nyland).

CASE STUDY 12

SUNSHINE COAST HIGHWAY IN DAVIS BAY

A section of the Sunshine Coast Highway in Davis Bay currently experiences periodic closures due to storm-surge flooding (Figure 23; Vadeboncoeur, 2014). For residents west of Davis Bay (approximately 20 000 people), closure of this highway blocks access to the Langdale Ferry Terminal, the only vehicle access point to Vancouver. For residents to the east (approximately 10 000 people) access to the regional hospital is blocked.

FIGURE 23: Storm surge on the Sunshine Coast Highway (Highway 101) at Davis Bay, February 6, 2006. *Photo courtesy of B. Oakford.*

Sea-level rise will amplify the impact of storms and could result in substantial erosion and structural damage to both the road and the power and gas lines that follow it. A 1 m storm surge that occurs in association with a 1 m rise in sea level would raise water levels nearly 1 m above the existing roadway, resulting in significant flooding in the surrounding area (Figure 24). To respond to this increasing risk of flooding, the Sunshine Coast Regional District, in collaboration with the province, is considering the eventual relocation of this stretch of highway through a new connection to a renovated existing road located at a higher elevation.

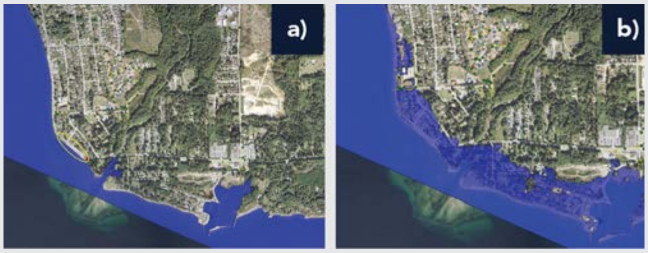

FIGURE 24: Sea-surface height (in purple) during the February 2006 storm surge on the Sunshine Coast Highway (Highway 101) at Davis Bay **a)** and during a 1 m storm surge with a 1 m of sea-level rise **b)**. (N. Vadeboncoeur, unpublished data, *base image from* Google, 2015).

4.3.4 BC FERRIES

Passenger ferry services operated by BC Ferries transport more than 20 million people each year to 49 terminals on 40 routes. Many ferry terminals are located in sheltered bays, while some have moderate exposure to wind and waves. However, the major terminal at Tsawwassen, which connects the lower mainland with southern Vancouver Island and the Gulf Islands (i.e., Victoria, Nanaimo), is situated in a location highly exposed to the Strait of Georgia.

Sea-level rise and increased exposure to storms present challenges to terminal infrastructure, including docks and access roads. Weather-related sailing delays and cancellations are relatively uncommon in British Columbia, affecting roughly 0.5% of all trips (BC Ferries, 2013). Although climate change increases the risk of such delays, it is unlikely that this will have a noticeable impact on the average British Columbian because weather accounts for only 6% of all delays or cancellations (BC Ferries, 2013). Increased storminess may present a challenge for remote communities that depend on ferry service for food and supplies if relatively infrequent (e.g., weekly) service is interrupted.

5 ADAPTATION PLANNING

Reactive approaches have traditionally dominated responses to changing environmental conditions in British Columbia (Walker and Sydneysmith, 2008). This is beginning to change. Several local governments have begun planning for the proactive management of sea-level rise (Section 4.2.2). Although adaptation is a shared responsibility between all orders of government, industry, nongovernment organizations and civil society (e.g., Bizikova et al., 2008), local governments have a particularly strong role to play with respect to adapting to sea-level rise along Canada's Pacific coast. Legislation enacted in 2004 placed the construction and maintenance of sea dikes and the designation of flood plains under municipal jurisdiction. As a result, there are now nearly 100 dike authorities in British Columbia, and each municipality is largely responsible for their own adaptation to ocean hazards.

Updating risk-management policies of local governments in British Columbia is one step that could help enhance climate resilience (Swanson and Bhadwal, 2009). However, as has been observed across Canada, this approach can be limited by the capacity of local governments to initiate adaptive actions and by their ability to actually implement proposed actions to enhance resilience (e.g., Burch, 2010).

Considerable work to advance adaptation in British Columbia has provided municipal decision makers with information resources on the potential impacts of a changing climate (e.g., Burch and Robinson, 2007; Harford, 2008; Burch et al., 2010; Ausenco Sandwell, 2011b, c; Delcan, 2012; Forseth, 2012; Arlington Group et al., 2013; Hill et al., 2013). However, municipal climate change adaptation is still relatively new, and several complicating issues that have commonly been raised by local governments have yet to be addressed completely. These include the need for cross-scale institutional collaboration on adaptation (i.e., the province, local governments and First Nations), the availability of information on local impacts, and the legal implications of taking action. The following sections summarize these concerns.

5.1 EVOLVING POLICIES ON COASTAL FLOODING AND SEA-LEVEL RISE

Existing flood policies in British Columbia were designed primarily to deal with flooding associated with spring snowmelt in rivers and ocean-storm surges. These policies assume that the timing and magnitude of riverine flooding, and the height of future storm-surge flooding, would remain in line with the historical record. However, these assumptions of climate stability are no longer appropriate and policies are therefore under review. The nature of future changes in both riverine and coastal flooding will vary, sometimes significantly, across coastal British Columbia. For example, in rainfall-dominated regimes, streamflows are expected to decrease on the south coast but increase in the north (Section 2.3). Storm-surge flooding will also increase in magnitude as a result of sea-level rise, with recent analyses calculating the elevation change needed to maintain the present frequency of flooding (Zhai et al., 2014). Sea-level rise leads to larger, more powerful waves reaching shorelines, potentially overtopping dikes and increasing erosion (as in the case of the Corporation of Delta; Shaw et al., 2006).

Local governments in British Columbia have autonomy over land-use planning within their jurisdictions, including the ability to manage land use and approve development in flood-prone areas, designate floodplains and set building requirements (Table 6). The *Local Government Act* grants this authority and allows local governments to use a variety of policy tools, such as Official Community Plans, bylaws, development permits, building permits and zoning restrictions, to plan for adaptation (e.g., Richardson and Otero, 2012). Potential actions for integrated flood-hazard management in British Columbia (Table 6) are outlined below.

5.1.1 LAND USE

Local governments control land-use and construction permitting in flood-prone areas via zoning bylaws. Local governments can, and often do, impose special requirements for construction (such as minimum Flood Construction Levels). The recently updated British Columbia guidelines for development in flood-risk areas clearly identifies the need for Flood Construction Levels in line with the increased risk presented by sea-level rise (Ausenco Sandwell, 2011b). Many municipalities throughout the province (e.g., the City of Vancouver) are revising their requirements for new buildings. However, existing buildings remain at risk of inundation. Solutions to flood risk that include both zoning and permitting are currently being considered throughout the coastal region (Section 5.1.2).

5.1.2 FLOOD PROTECTION

Provincial guidance on management of coastal-flood hazard is currently outlined in *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use*, which includes three components: 1) *Sea Dike Guidelines* (Ausenco Sandwell, 2011c); 2) *Guidelines for Management of Coastal Flood Hazard Land Use* (Ausenco Sandwell, 2011b); and 3) *Draft Policy Discussion Paper* (Ausenco Sandwell, 2011a).

- The *Sea Dike Guidelines* provide direction for the design of protective dikes for low-lying lands exposed to coastal-flood hazards. They recommend that the heights of dikes, sea walls, and flood construction levels of buildings be revised to accommodate a sea-level rise of 0.5 m by the year 2050, 1.0 m by 2100 and 2.0 m by the year 2200 (Ausenco Sandwell, 2011c).
- The *Guidelines for Management of Coastal Flood Hazard Land Use* support the development and implementation of local-government land-use management plans and subdivision-approval processes and planning in areas exposed to coastal-flooding hazards, and provide a list of land-use management tools (Ausenco Sandwell, 2011b).
- The *Draft Policy Discussion Paper* is an attempt to bridge the gap between science and the practical application of measures to address climate change in coastal BC (Ausenco Sandwell, 2011a).

TABLE 6: Overview of responsibilities and policies of relevance to flooding in British Columbia.

Jurisdiction	Land use	Flood protection	Flood response and recovery
Federal	▪ National parks ▪ Indian reservations ▪ Department of National Defence sites	▪ Infrastructure funding	▪ Disaster financial assistance ▪ Emergency management*
Provincial	▪ Crown lands ▪ Subdivision approvals outside municipalities ▪ Construction-setback guidelines ▪ Flood Construction Levels guidelines	▪ Approval of municipal flood-protection works ▪ Technical guidance for municipalities ▪ Infrastructure funding	▪ Disaster financial assistance ▪ Emergency management
Local	▪ Municipal land-use planning/ zoning ▪ Internal subdivision approvals ▪ Construction-setback implementation ▪ Flood Construction Level implementation	▪ Construction/ management of protective works ▪ Infrastructure funding	▪ Emergency management

* This in not a normal part of federal responsibility, but this level of government has provided support via the armed forces in extreme cases.

This work was undertaken as a first step toward updating the 2004 guidelines published under the *Environmental Management Act*. Since the release of these reports, the BC Ministry of Environment has been consulting with stakeholders and the Union of British Columbia Municipalities on implementation. It is important to note that, while the maximum likely increase in sea level by 2100 presented in this report is less than the 1 m estimate referenced in the provincial climate change adaptation guidelines, the guidelines provide a margin of safety that allows for possible additional sea-level rise resulting from factors with significant uncertainty, such as contributions from the Antarctic Ice Sheet.

Although upgrading dike infrastructure will likely be required for the protection of many residences, commercial/industrial buildings and public infrastructure (e.g., Delcan, 2012), soft-armouring approaches may be more effective and less costly in some cases than hard armouring. Some communities have already begun to implement these alternative approaches with success (e.g., North Vancouver, Section 4.2.2).

5.1.3 DISASTER RECOVERY

Recovery from a disaster can, in some situations, provide an opportunity for implementation of adaptation measures as part of the rebuilding process. The Disaster Financial Assistance Program of Emergency Management BC can fund 80% of eligible (uninsured) damages incurred due to a disaster, up to a maximum of $300 000 for homeowners, residents, small-business owners, farm owners and charitable organizations. Additional disaster assistance for local governments may be available on a case-by-case basis from both the federal and provincial levels. Given the present level of flood exposure in the province, it is likely that private-property owners, together with all levels of government, will incur increasing costs as a result of flood events.

Infrastructure funding is an important facilitator of adaptation to sea-level rise. Federal and provincial governments have, in the past, partnered to fund infrastructure projects that provide flood protection to communities across BC. The Provincial Flood Protection Program and the Disaster Mitigation Category of the Federal Building Canada Plan are good examples of this. In British Columbia, the Provincial Flood Protection Program funds infrastructure projects based on applications received from local governments, and funding of some projects has, in the past, been shared equally between federal, provincial and local governments. Communities in British Columbia can also access infrastructure funding through the Federal Gas Tax Fund, BC utilities and nonprofit organizations, including the Community Energy Association, BC Hydro and the BC Stewardship Council.

5.2 COMMUNITY PERSPECTIVES

Recent studies, and conversations with local-government officials from across coastal British Columbia, have revealed several concerns regarding the development and implementation of climate change adaptation measures (e.g., Burch, 2010; Burch et al., 2010; Vadeboncoeur and Carlson, work in progress). The concerns expressed include a perceived absence of specific information on local climate impacts, a lack of capacity to develop and implement adaptation strategies, and potentially negative political and legal consequences of both action and inaction. These are outlined below.

5.2.1 LOCAL DATA NEEDS

Sea-level rise has not yet been integrated into many existing floodplain maps or planning activities. This is because of both data availability and the capacity of local governments for data analysis. For example, approximately 25% of coastal communities in BC have no access to LiDAR data for detailed flood mapping and just over half (54%) of communities with access to digital geospatial data (LiDAR and/or Orthophoto) have not used the data in planning (Vadeboncoeur, 2015). Most of the population of coastal BC (75%) lives in an area where LiDAR data are available, but this is divided asymmetrically between Metro Vancouver and the Capital Regional District (98.8% coverage, by population) and the rest of the coast (39.1% coverage, by population; Vadeboncoeur, 2015). Despite provincial guidelines that recommend adapting to 1 m of sea-level rise by the year 2100 and 2 m by 2200, some local governments have delayed adaptation planning until more detailed information is available on the projected local extent of sea-level rise in their communities. New data on regional sea-level rise (Section 2.3 and *see* Chapter 2; James et al., 2014) provide communities with updated estimates of long-term local changes to sea level and can be used to help predict changes in potential flooding. Coastal regions lacking detailed topographic information, such as LiDAR data, may benefit from new surveys.

Local governments have also expressed concerns over the potential impacts of heavy precipitation events. These include the need for improved local data on intense precipitation events, as well as factors affecting slope stability and the potential for landslides. Municipalities also have concerns over the potential for potable-water shortages.

Publicly available data and tools on potential climate changes and associated impacts in British Columbia include an online database that provides floodplain maps, a water-balance model (www.bc.waterbalance.ca) and two online planning tools to help communities understand climate changes: Plan2Adapt (www.plan2adapt.ca) and the BC Climate Action Toolkit (www.toolkit.bc.ca). Communities can use these resources to customize outputs for their geographic region, thereby providing a good characterization of the potential level of risk a community can expect to face as a result of changing climate.

5.2.2 UNINTENTIONAL CONSEQUENCES OF ADAPTATION

Local governments have also expressed concern over how designating floodplains may impact the property values of their constituents. Properties lying within designated floodplains are generally less valuable than equivalent ones outside floodplains, particularly after storms that have caused damage (Bin and Polasky, 2004; Bin and Landry, 2013). However, the reduction in value has been observed to disappear within the 5–6 years following a storm (Bin and Landry, 2013), suggesting that the desirability of waterfront lots may continue to increase property values even when subjected to periodic storm damage (so long as damages are followed by a period of relative calm). To date, the real-estate market in British Columbia does not appear to attach a flood-risk premium to at-risk areas, suggesting that buyers are either uninformed about, or more likely insensitive to, flood risks.

Legal liability is a concern for local governments. Liability issues could arise in the form of negligence or nuisance claims if, for example, it can be proven that reasonable care toward its residents has not been exercised. This topic is explored in Case Study 13.

CASE STUDY 13:

ADAPTATION AND LEGAL LIABILITY: CONCERNS FOR LOCAL GOVERNMENTS

The legal framework in which coastal municipalities operate may condition or determine some adaptation responses because legal liabilities, both demonstrated and perceived, can be relevant to planning. As elsewhere in Canada, local governments in BC derive their powers and related duties from provincial legislation. They may also be affected by federal and provincial government requirements that can direct planning decisions at the local level (e.g., building codes). In some cases, this exercise of federal or provincial jurisdiction may align with or support local government policies and objectives; in other cases, it may pose barriers (Vadeboncoeur and Carlson, work in progress). As a result, adjacent municipalities within a region might have quite different approaches to the same set of issues.

The risk of legal liability, while far from being a dominant driver for adaptive responses to sea-level rise by local governments, does seem to be a factor to consider, given the potential financial impact. This is because local governments are subject to common law precedents developed through decisions of the Court, unless protected by statutory immunity or other provisions. There are examples of municipalities in Canada that have been targeted in class-action lawsuits to recover property damage caused by extreme climate events.

Local governments may be subject to liability for extreme events, such as flooding, through both negligence and nuisance claims. Such claims may be based on local government decisions and actions related to design, building, operation and inspection of infrastructure in cases where infrastructure fails or is in some way hazardous or damaging to people or property. Given currently available information regarding sea-level rise, coastal flooding may be seen as a factor that a local government should take into account in operational decisions and actions, where relevant.

Local governments in British Columbia enjoy statutory immunity under the *Local Government Act* where sewer systems, water or drainage facilities, dikes or roads break down or malfunction, and interfere with private-property use. However, BC courts have found that this immunity does not apply where property damages arise from a design that is inadequate for the purpose it is meant to fulfill. Infrastructure built today may be affected by sea-level rise in the future and could present a liability if that rise is not factored into design. In order to minimize liability and avoid the high capital cost of avoidable upgrades or relocations, local governments require good technical information about infrastructure vulnerability. This information will also be relevant for the siting of new infrastructure to minimize risks related to inundation and storm damage.

Risks of legal liability associated with possible infrastructure failure may be an additional factor in catalyzing action on the part of local governments to prepare for rising sea levels.

6 CONCLUSIONS

Current and anticipated impacts of climate change on coastal British Columbia are a result of both direct impacts from changing atmospheric conditions and the indirect, climate-driven alterations to coastal ecosystems. These changes present risks and challenges to local governments and First Nations, and represent a risk to the broader British Columbia economy. Key conclusions emerging from this chapter are summarized here.

CLIMATE CHANGE IS ALREADY IMPACTING THE COAST

Climate records indicate that there has been a gradual warming trend in coastal British Columbia since 1900, particularly in winter. Higher precipitation has been observed in winter and fall, while decreased summer rainfall may influence periods of seasonal drought. Increased winter temperatures have led to a decline in precipitation that falls as snow, resulting in increased runoff and less water storage as snow and ice at high elevations, exacerbating summer water shortages in some years for some areas.

Geological effects will amplify or offset the impact of sea-level rise on coastal communities. In some regions, crustal uplift will cause relative sea levels to be less than the global average, whereas subsidence in others will result in accelerated sea-level rise. Increased storminess will exacerbate the problems presented by sea-level rise because deeper water allows waves to gain more power, exposing coastal settlements to greater risk of storm damage and flooding.

CLIMATE CHANGE WILL INCREASE EXISTING STRESSES ON BRITISH COLUMBIA'S FISHERIES

Although the fishing industry has changed significantly during the past two decades, having decreased in size and developed a substantial commercial-capture component, it remains an important part of the social and cultural identity of many British Columbians.

The distribution of the availability of some endemic fish species will likely change as the range of marine species shifts northward. It is possible that the southern range of healthy salmon stocks will decline while their northern range expands. If this occurs, the species available for wild capture, sport and First Nations fishers will change, particularly in the southern part of the province. Farmed salmon would not likely be affected by these distributional changes, but commercial capture operations could still be impacted by climate change via increased risk of storms (that can damage net pens) and warmer waters (that can increase risk of disease).

Shellfish are affected by increased ocean acidity. Acidification, combined with increased water temperature, affects shellfish by limiting their ability to reproduce and decreasing their (vertical) habitable range.

The commercial-capture fishery, its regulators and the market have responded to the major declines in salmon and herring by increasing use of other commercial fish. This suggests that the British Columbia fishery can cope with changing availability of target species. Information on First Nations fisheries is scarce, and the pivotal cultural importance of salmon (and activities associated with its catch, processing and distribution) suggests that there is limited ability to adapt to sudden fluctuations, or a steady decline, in salmon runs. Adaptation has been supported in some First Nations communities, but concrete proactive actions remain rare.

STRATEGICALLY IMPORTANT INFRASTRUCTURE IN BRITISH COLUMBIA FACE NEAR- AND LONG-TERM CHALLENGES FROM CLIMATE VARIABILITY AND CHANGE

Climate change presents a suite of risks to critical infrastructure, such as Port Metro Vancouver and Vancouver International Airport, and regionally important infrastructure, such as highways, and electricity and gas lines. The anticipated expansion of primary-resource development within the province, and the associated infrastructure needs, including export terminals along the north coast, will increase exposure to climate impacts. Although related research remains limited, these industries have demonstrated understanding of the risks that climate change presents to their operations and are either taking steps to address these (e.g., Vancouver International Airport) or are comfortable with their preparations to date and possess the data required for an updated risk assessment when it is deemed appropriate (e.g., Port Metro Vancouver).

THERE ARE REGIONAL DIFFERENCES IN VULNERABILITY

Vulnerability to climate change reflects the social, cultural and geographic diversity of coastal British Columbia. For example, salmon fishers in the southern part of the province will experience the impacts of increased stress on fished stocks earlier than northern fishers. Communities exposed to long stretches of open water will experience more risk from storms than those in more sheltered areas. First Nations peoples and other communities where primary incomes are based on salmonid fisheries will experience effects related to a decline in commercial catch similar to other groups, but they would also be affected culturally and socially if their subsistence catch were to also decline.

There are also differences between rural and urban communities. The former often rely more heavily on natural resources, while the latter have more diversified economies and have greater capacity to respond to risks. As such, rural adaptation often requires an additional emphasis on managing the socio-economic impacts of changes to resource- and place-based economics.

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APPENDIX A

SEA-LEVEL PROJECTIONS FOR SELECTED LOCATIONS IN THE WEST COAST REGION

Projected relative sea-level changes to 2100 are provided here for 19 locations shown on the accompanying map (Figure A1) for the West Coast region (*after* James et al., 2014–2015; Section 2.4 and *see* Chapter 2 for details of projections). The sea-level projections (Figure A2) are based on the IPCC Fifth Assessment Report (Church et al., 2013a, b) and were generated using vertical crustal motion derived from GPS observations.

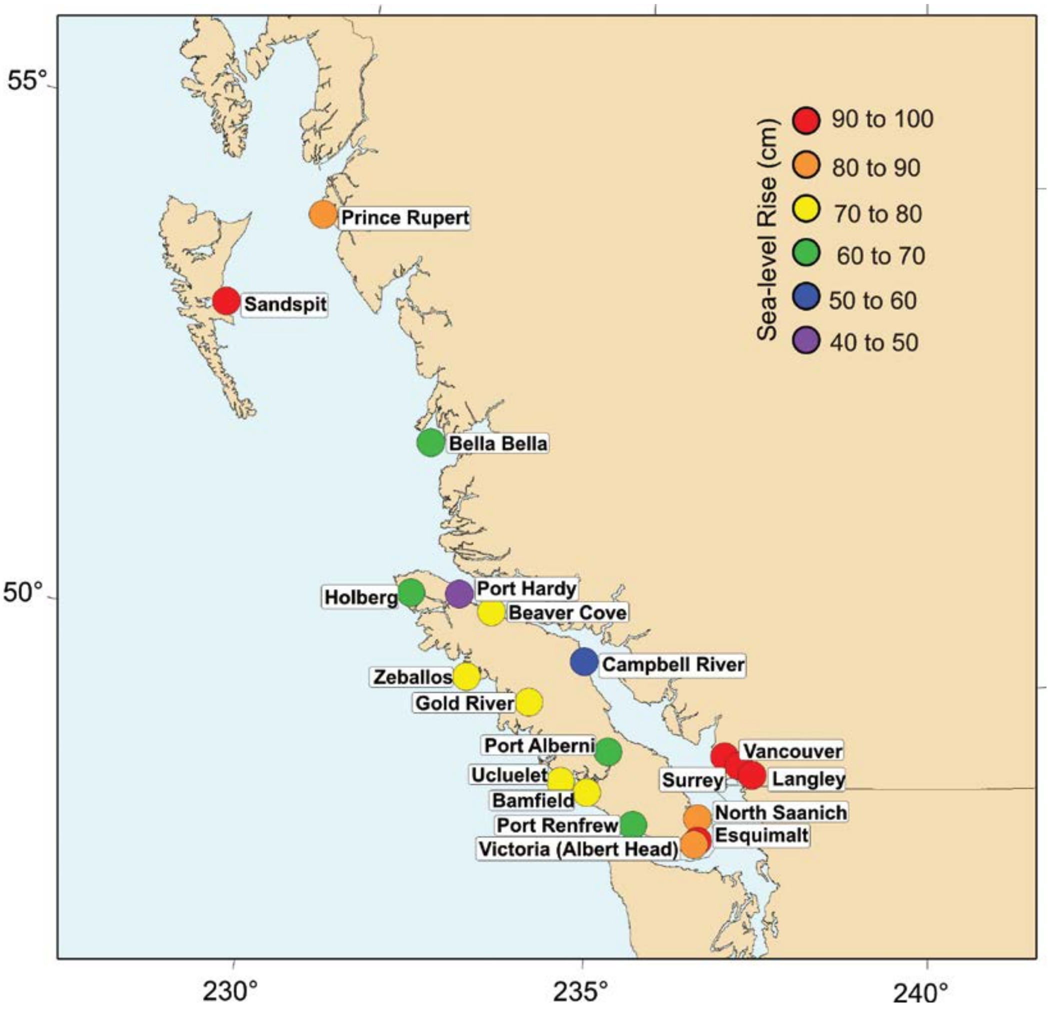

FIGURE A1: Locations for which sea-level projections are provided through the 21st century (Figure A2). Dots are colour coded to indicate the projected sea-level change at 2100 for the 95th percentile of the high-emissions scenario RCP8.5 (*after* James et al., 2014-2015)

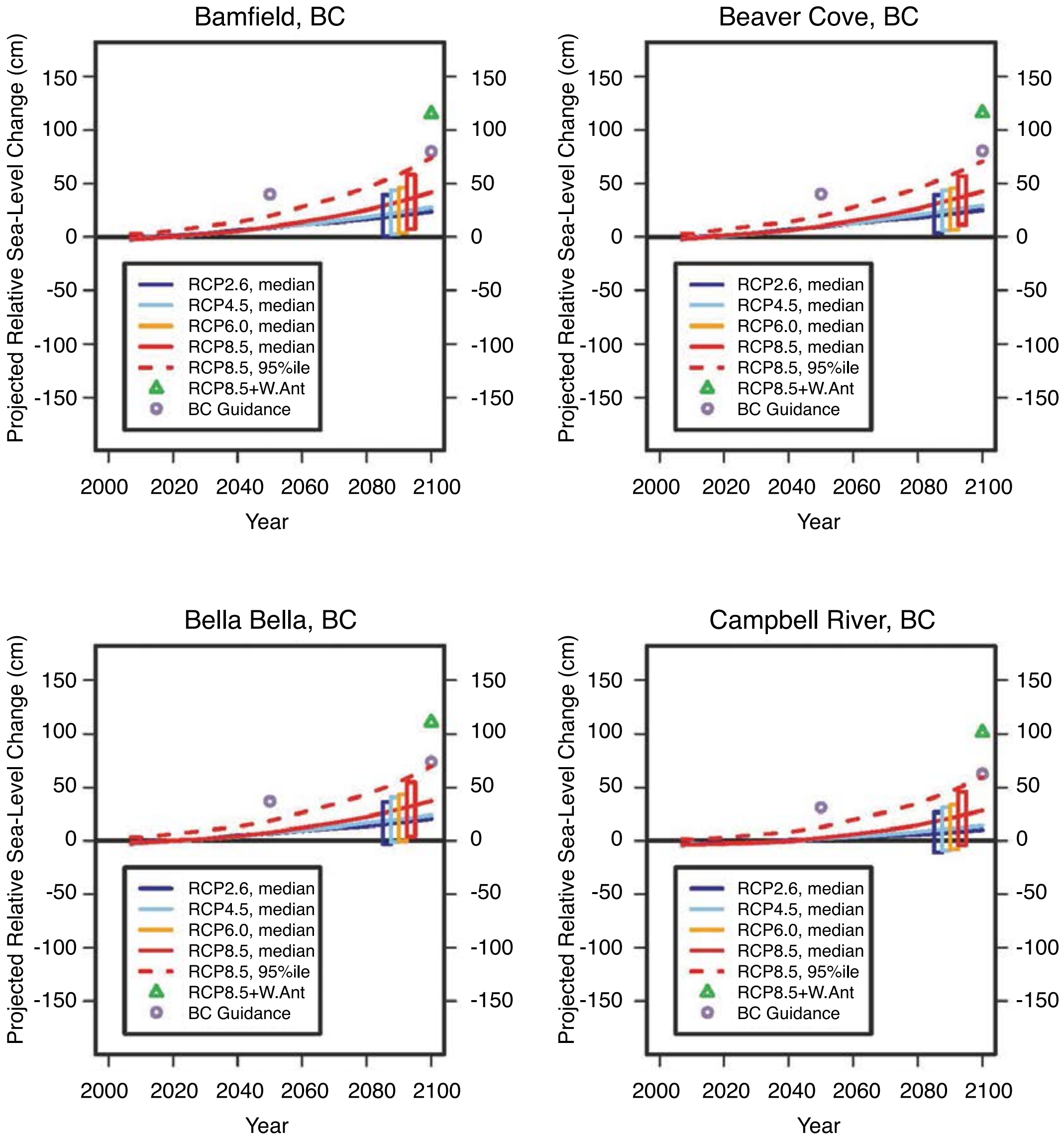

FIGURE A2: Projected relative sea-level change through the 21st century for selected locations in the West Coast region (*after* James et al., 2014–2015). RCP2.6 is a low-emissions scenario, RCP4.5 is an intermediate-emissions scenario and RCP8.5 is a high-emissions scenario. The projected value at 2100 is also given for the high-emissions plus Antarctic ice-sheet reduction scenario, an augmented scenario, in which West Antarctica contributes an additional 65 cm to the median projected value of the high-emissions scenario (RCP8.5+W.Ant; green triangle). Rectangles show the 90% confidence interval (5–95%) of the average projection for the period 2081–2100 and include RCP6.0. The dashed red line gives the 95th percentile value for the high emissions scenario. The allowance for sea-level rise (BC Guidance) specified by the government of British Columbia is also given (Ausenco Sandwell, 2011b).

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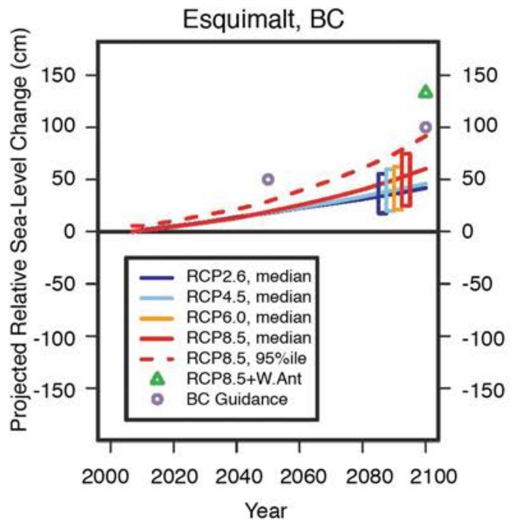

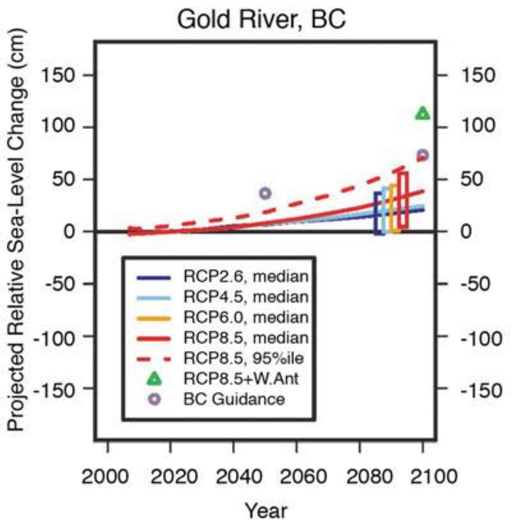

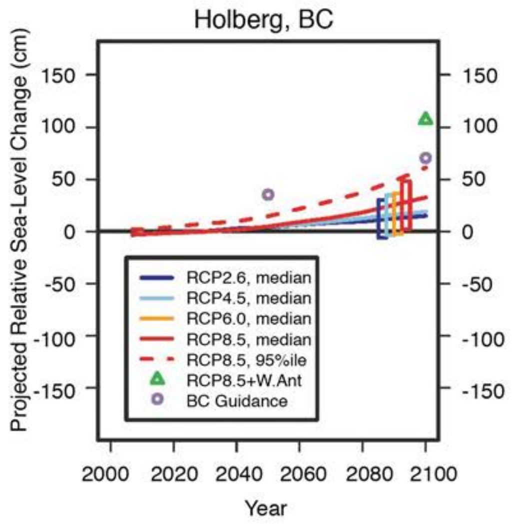

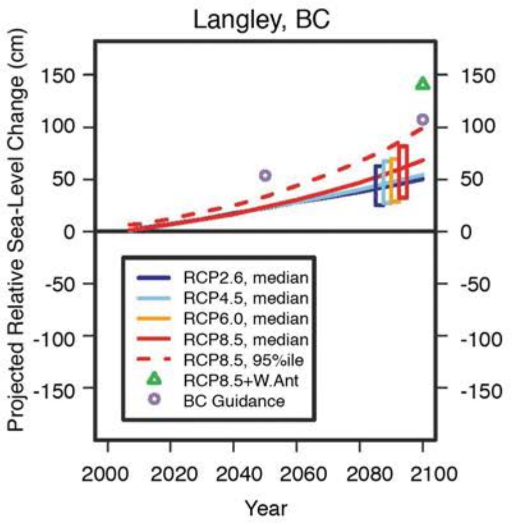

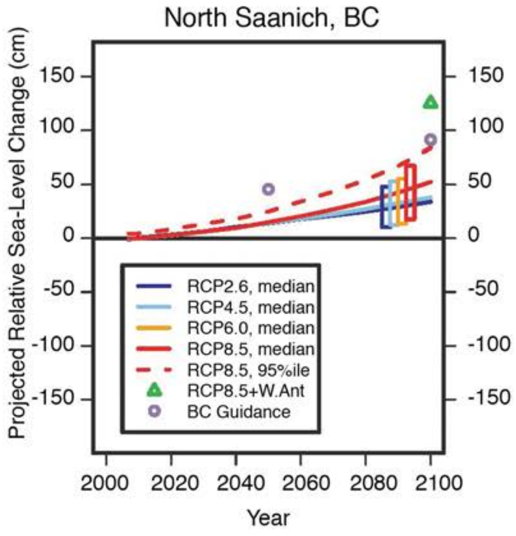

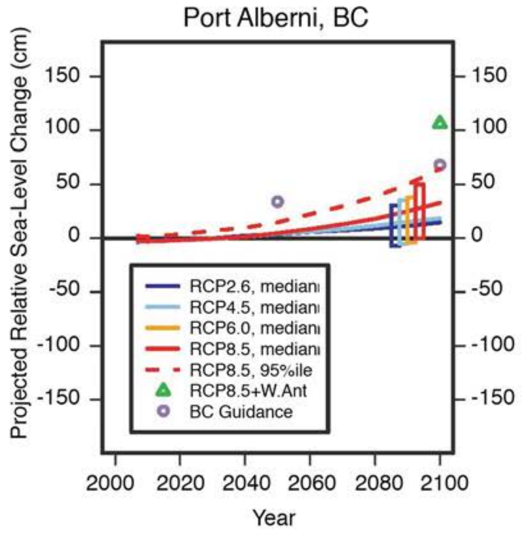

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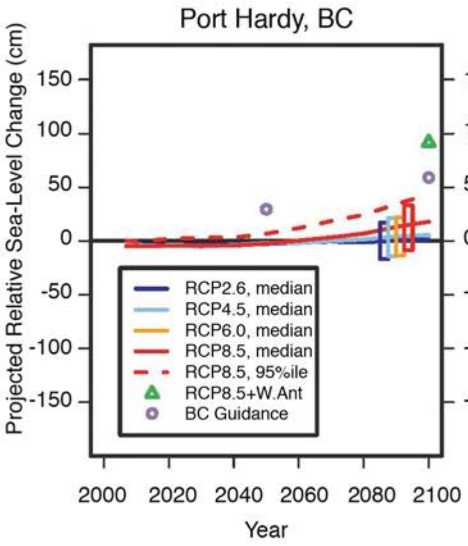

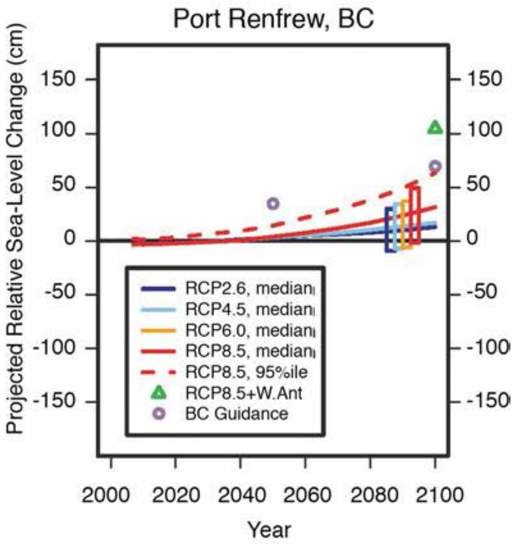

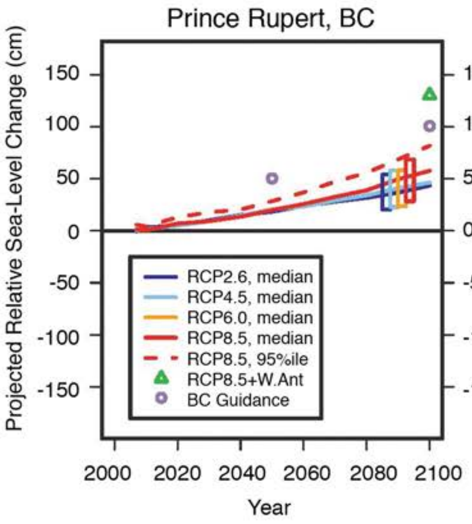

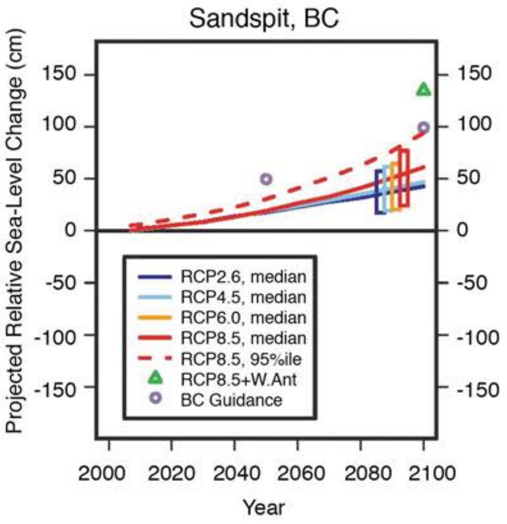

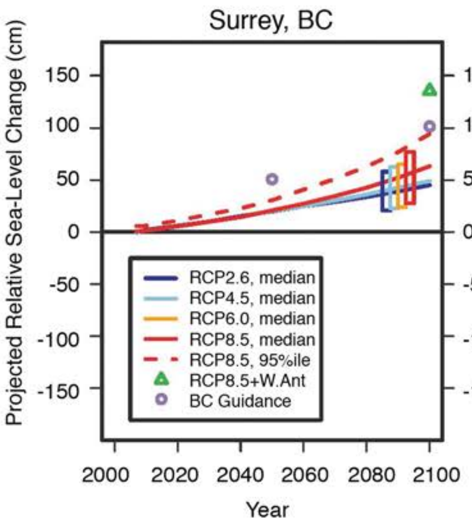

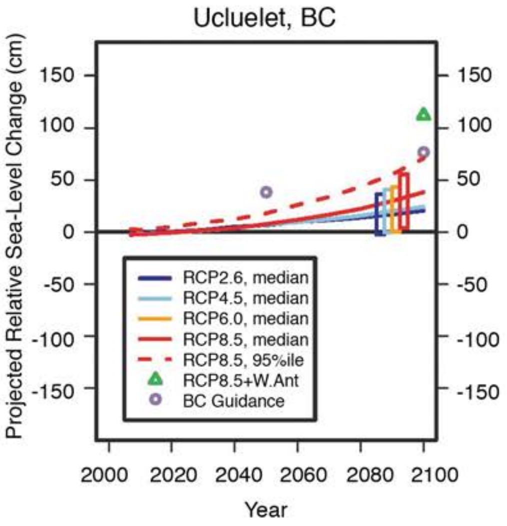

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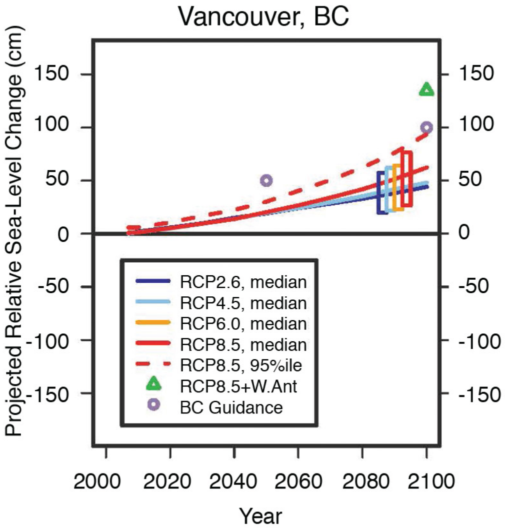
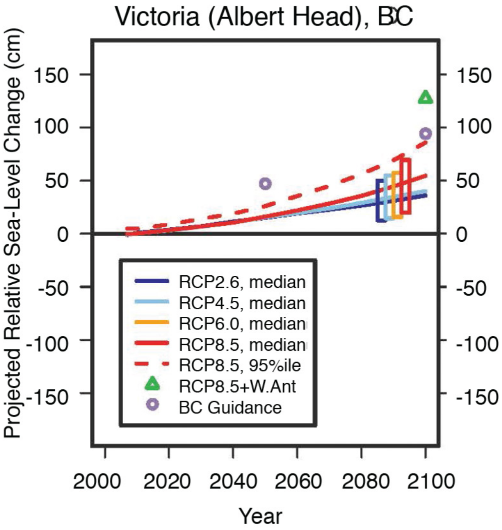
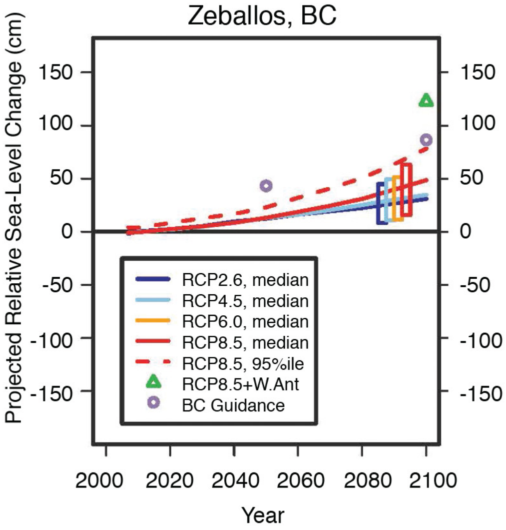

Vancouver, BC
Projected Relative Sea-Level Change (cm)
150
100
50
0
-50
-100
-150
RCP2.6, median
RCP4.5, median
RCP6.0, median
RCP8.5, median
RCP8.5, 95%ile
RCP8.5+W.Ant
BC Guidance
2000
2020
2040
2060
2080
2100
Year


Victoria (Albert Head), BC
Projected Relative Sea-Level Change (cm)
150
100
50
0
-50
-100
-150
RCP2.6, median
RCP4.5, median
RCP6.0, median
RCP8.5, median
RCP8.5, 95%ile
RCP8.5+W.Ant
BC Guidance
2000
2020
2040
2060
2080
2100
Year


Zeballos, BC
Projected Relative Sea-Level Change (cm)
150
100
50
0
-50
-100
-150
RCP2.6, median
RCP4.5, median
RCP6.0, median
RCP8.5, median
RCP8.5, 95%ile
RCP8.5+W.Ant
BC Guidance
2000
2020
2040
2060
2080
2100
Year