

# SYNTHESIS

**Lead Authors:**

Donald S. Lemmen and Fiona J. Warren (*Natural Resources Canada*)

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## SUMMARY

Coasts are an important component of the Canadian identity, economy and culture. Fronting on three oceans—Atlantic, Arctic and Pacific—Canada’s coasts, the longest in the world, are diverse and dynamic regions whose biodiversity, beauty and resources contribute to the country as a whole. The impacts of climate change on Canada’s coasts, which extend far beyond changes in sea level, present both challenges and potential opportunities for coastal communities, ecosystems and economic activities. How we adapt to the coming changes will be critical to the sustainability and continued prosperity of Canada and its coastal regions. The following points represent high-level conclusions from *Canada’s Marine Coasts in a Changing Climate*, and are discussed further in this synthesis:

- Changing climate is increasingly affecting the rate and nature of change along Canada’s highly dynamic coasts, with widespread impacts on natural and human systems.
- Recent extreme weather events demonstrate the vulnerability of coastal infrastructure.
- Changes in the extent, thickness and duration of sea ice, both in the North and in some areas of the East Coast region, are already impacting coasts, ecosystems, coastal communities and transportation.
- Sea-level changes will vary significantly across Canada during this century and beyond. Where relative sea level is rising, the frequency and magnitude of storm-surge flooding will increase in the future.
- Knowledge of climate risks and the need for adaptation in coastal areas is increasing, with many examples of local and regional governments in Canada taking action on adaptation.
- A range of adaptation measures will be needed in most settings to address the complex array of changes. Alternatives to hard coastal-protection structures can be effective in addressing coastal erosion and flooding in many areas.
- It is imperative that future development be undertaken with an understanding of the dynamic nature of the coast and changing coastal risks. Monitoring and assessment of the effectiveness of actions taken to date, as well as research to fill data and knowledge gaps, would help inform sustainable planning and development.

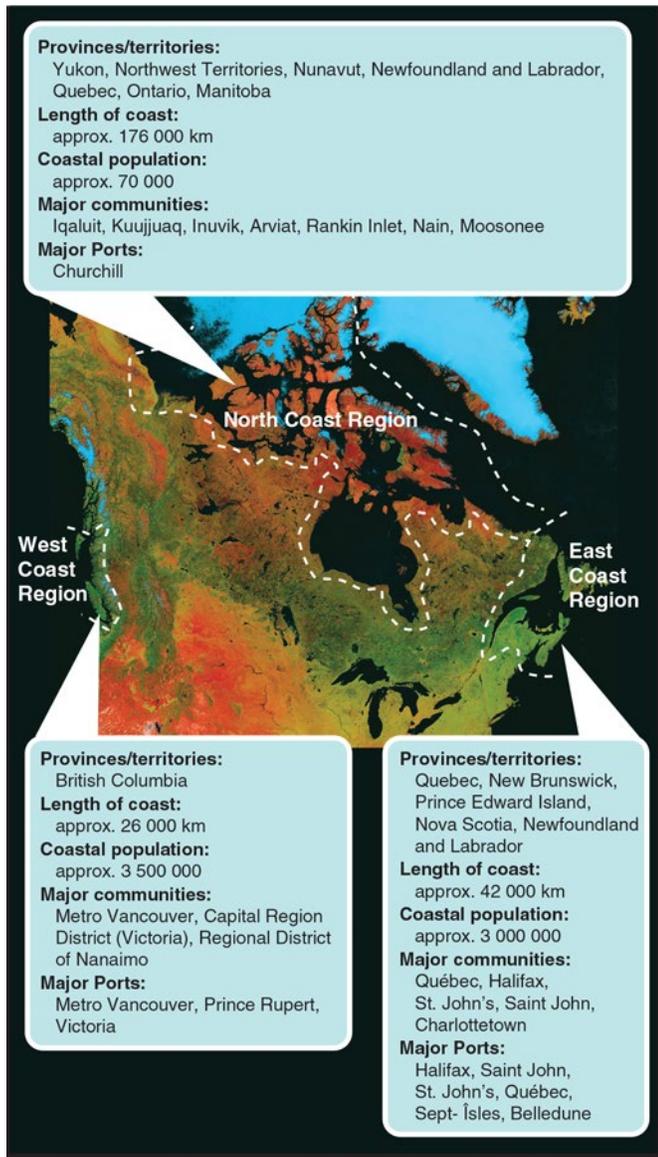
## INTRODUCTION

Canada is a coastal nation. All provinces and territories, with the exception of Alberta and Saskatchewan, share in the approximately 243 000 km of coastline (Taylor et al., 2014). Indigenous peoples have lived along Canada’s coasts and utilized coastal resources for thousands of years, and many First Nation, Métis and Inuit communities retain very close ties to the coast. Today, about 6.5 million Canadians live near our marine coasts, and more than \$400 billion in goods are shipped annually through Canadian ports (Association of Canadian Port Authorities, 2013).

This report takes a landscape approach in examining Canada’s marine coasts. While focus is placed on the shoreline as the interface between land and water, the scope of interest extends landward and oceanward to the degree that those areas affect the sustainability and well-being of coastal communities and ecosystems.

This report divides Canada’s marine coasts into three large regions: East Coast, North Coast and West Coast (Figure 1). It is important to recognize that there is tremendous variability both among and within these regions. For example, the North Coast region (which includes about 70% of Canada’s coastline) is very sparsely populated; the majority of residents are Inuit, First Nations or Métis; and sea ice is a defining element of the coast for much of the year. The East Coast region is characterized by several cities and an abundance of small towns and hamlets, with a diverse economy in which coastal resources continue to play an important role. The population of the West Coast region is concentrated in British Columbia’s lower mainland and southeastern Vancouver Island, with the number of residents and built-environment asset value of the greater Vancouver area far exceeding that of any other part of Canada’s marine coast.

Science assessments at global (e.g., IPCC, 2007, 2014) and national (e.g., Lemmen et al., 2008; Warren and Lemmen, 2014) scales highlight the importance of understanding and addressing climate change impacts in coastal regions. Globally, coastal flooding could displace hundreds of millions of people in the current century, with the annual costs for adaptation measures such as new dike construction, dike maintenance and beach nourishment estimated to be US\$25–270 billion per year by 2100 (Wong et al., 2014). Within Canada, climate change (Box 1) presents a range of risks, with higher temperatures, changing precipitation patterns and storminess, rising sea level and diminishing sea ice being the key climate changes discussed throughout this report. The magnitude, importance and sometimes direction of these changes vary both among and within the three regions.



**FIGURE 1:** The three coastal regions used in this report.

*Canada's Marine Coasts in a Changing Climate* complements previous science assessments in this series: *From Impacts to Adaptation: Canada in a Changing Climate* (Lemmen et al., 2008), which presents a regional analysis of impacts and adaptation for Canada as a whole; and *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Warren and Lemmen, 2014), which is organized by themes and economic sectors. Readers are directed to these earlier assessments for a more complete description of some of the concepts presented in this report. This synthesis draws on information discussed in the individual chapters of *Canada's Marine Coasts in a Changing Climate*, which include an overview of the geological and physical aspects of the coast (Chapter 2); a chapter on the environmental and societal sustainability of Canada's marine coasts (Chapter 3); three regional chapters that examine issues in Canada's East, North and West Coast regions (Chapters 4, 5 and 6, respectively); and a concluding chapter that addresses frequently asked questions (Chapter 7). The key findings of Chapters 4 to 6 are summarized in Box 2. The rest of the synthesis is structured around high-level conclusions (listed in the 'Summary') supported by examples and insights from an integrative analysis of the chapters of the report.

## BOX 1 WHAT IS CLIMATE CHANGE?

The term climate change is used in this report to refer to any change in climate over time, whether it is the product of natural factors, human activity or both. Analysis at the global level demonstrates that warming of the Earth's climate system is unequivocal, and that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20<sup>th</sup> century (IPCC, 2013). Climate change is distinct from natural climate variability, which includes short-term phenomena such as the El Niño/Southern Oscillation. The term 'changing climate' is used frequently throughout this report to highlight that these changes are ongoing.

## ADDRESSING CLIMATE CHANGE

Enhanced action to address climate change is a global commitment solidified in the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change. Such action involves both reduction of greenhouse gas emissions (mitigation) and adjusting to unavoidable climate impacts (adaptation). Adaptation is undertaken to reduce the negative impacts of climate change and to take advantage of opportunities that may be presented. In human systems, adaptation refers to changes in our decisions, activities and thinking because of observed or expected changes in climate. This report focuses on processes and actions associated with planned adaptation— deliberate decisions based on understanding of ongoing and anticipated climate changes.

## BOX 2

# SUMMARY OF REGIONAL CHAPTER KEY FINDINGS

## CHAPTER 4: PERSPECTIVES ON CANADA'S EAST COAST REGION

**Air temperatures, sea-surface temperatures and ocean acidity have all increased in the region during the past century, while sea-ice cover has decreased.** Projected climate changes through the 21<sup>st</sup> century include continued warming of air and water temperatures, and increased precipitation, acidification and water stratification. Sea level will rise, with significant regional variability. Sea ice will decrease in area, thickness, concentration and duration, with volume likely to be reduced by more than 95% by the end of the 21<sup>st</sup> century.

**Sea-ice cover and sea-level rise are key determinants of coastal erosion rates.** Increases in coastal erosion have been documented along many coasts in the region during years characterized by mild winters and low ice coverage. Future coastal-erosion rates will likely increase in most areas.

**There are many adaptation measures that promote the resilience of coastal areas.** These include protection, revegetation and stabilization of dunes; maintenance of sediment supply; and provision of buffer zones, rolling easements or setbacks that allow the landward migration of the coastline.

**Although hard coastal defence structures may be necessary to address sea-level rise and coastal flooding in some situations, particularly in urban areas, such structures disrupt coastal processes** and can exacerbate erosion, sedimentation and coastal squeeze, leading to degradation and loss of coastal habitats and ecosystem services. Retreat, sand nourishment and managed realignment represent alternatives to hard coastal-defence structures.

**Experience in the East Coast region has shown that mechanisms such as setbacks, which control or prohibit coastal development, can be challenging to implement.** However, it is often even more difficult to remove and relocate buildings from an eroding coastline or flood-susceptible area. Selection of appropriate adaptation options may be particularly challenging in unincorporated areas where summer cottages, secondary homes or principal dwellings are established parallel to the shore in a ribbon fashion.

**Provinces and communities across the region have made advances in identifying vulnerabilities to climate change impacts through collaboration with academia, the private sector and nongovernmental organizations.** Many have begun planning for adaptation, while others have moved from planning to implementation of adaptation strategies, although this remains a challenge for many. Few are engaged in ongoing monitoring of the effectiveness of implemented adaptation strategies.

## CHAPTER 5: PERSPECTIVES ON CANADA'S NORTH COAST REGION

**The environment and socio-economic characteristics of the northern coast are unique.** Inhabited primarily by Indigenous populations living in small remote communities, Canada's northern coastline is vast, representing more than 70% of all Canadian coasts. The presence of sea ice is a defining feature of this coast, affecting transportation access, shaping geomorphological processes and providing a platform for culturally valued and economically important harvesting activities. Social, economic and demographic characteristics of northern coastal communities differ considerably from the Canadian average, with resource development and public administration being mainstays of northern economies.

**The northern coast is a hotspot for global climate change.** The region has experienced some of the most rapid climate change anywhere on the globe, and projected future climate changes for the northern coastline will continue to be significant. Impacts on the physical environment include declining sea-ice concentration, earlier ice break-up and later freeze-up, a lengthening of the ice-free open-water season, permafrost warming and thaw, coastal erosion, sea-level rise and changing weather patterns, including wind and waves.

**Northern coastal communities, ecosystems and economic activities are being affected by climate change impacts.** Many communities have a high sensitivity to climate change impacts, as they are situated on low-lying coasts and have infrastructure built on permafrost, economies strongly linked to natural resources and dependence on land-based harvesting activities. Negative impacts of climate change on a variety of sectors have been widely

documented across the northern coast. New opportunities associated with a longer ice-free shipping season are also recognized, but increased marine traffic also brings risks.

**Climate change will exacerbate existing vulnerabilities.** Vulnerability differs significantly by region and community and, within communities, as a function of geographic location, nature of climate change impacts and human factors. Capacity to manage climate change is high in some sectors, such as subsistence harvesting and health, but is being undermined by long-term societal changes. In other sectors, such as infrastructure, limitations in climate risk-management capacity (e.g., institutional, financial, regulatory) result in continuing high vulnerabilities.

**Northern coastal communities and industries are adapting.** Adaptation actions are already taking place in the North, with examples of adaptation planning documented across all levels of government. The effectiveness and sufficiency of the existing responses have not been evaluated, although barriers to adaptation, including limited resources, institutional capacity and a lack of 'usable' research, have been identified. Publicly available information on how the private sector is approaching adaptation is limited.

**Opportunities for additional adaptation are diverse.** Mainstreaming adaptation into ongoing policy initiatives and priorities to address underlying socio-cultural determinants of vulnerability can help address the risks posed by climate change to harvesting activities, culture and health. Adaptation actions targeted at specific climatic risks are also required, particularly to manage the impacts of climate change on community and industrial infrastructure.

## CHAPTER 6: PERSPECTIVES ON CANADA'S WEST COAST REGION

**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 (95<sup>th</sup> 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.

## **CHANGING CLIMATE IS INCREASINGLY AFFECTING THE RATE AND NATURE OF CHANGE ALONG CANADA'S HIGHLY DYNAMIC COASTS, WITH WIDESPREAD IMPACTS ON NATURAL AND HUMAN SYSTEMS.**

Coasts are naturally dynamic environments. While change is most evident in the natural environment, for example arising from intermittent extreme events such as storms that erode beaches and cliffs, and long-term changes in sea level and ecosystems (Chapter 2), the social and economic environments of Canada's coasts are similarly dynamic (Chapter 3). Although Canada's coastal economies were historically based on fisheries, agriculture, forestry and transportation, our coasts have become increasingly urbanized and economically diverse in recent decades. Development of offshore oil-and-gas (Chapters 4 and 5) and increased coastal tourism (Chapters 3, 4, 5 and 6) are examples of changing economic drivers that have affected the economies of coastal communities, and that reflect a broader economic shift toward commerce and innovation.

Changing climate is an additional, and increasingly important, driver of change in coastal regions. While the scientific literature is dominated by studies related to the impacts of extreme weather events (e.g., severe storms) and changes in sea level, there are many other climate-related changes that affect coastal regions. These include changes in temperature and precipitation patterns, storms, wave climate, sea ice, hydrology (including glacier melt) and ocean-water properties (e.g., temperature, salinity, acidification, hypoxia; Chapters 2, 4, 5 and 6). These changes exacerbate existing risks, bring new challenges and, in some cases, present opportunities. The degree and nature of the resulting damages or benefits depend largely on the success of adaptation measures.

Impacts on terrestrial and marine ecosystems remain poorly quantified (Chapter 7, FAQ 7). In some cases, ecosystems may be able to adapt naturally. In salt marshes, for example, if the rate of marsh accretion is able to keep up with sea-level rise, there would be limited impact (Chapters 2 and 4). However, where the rate of sea-level rise exceeds the ability of the marsh to accrete, or where onshore migration is blocked by natural or artificial barriers, loss of habitat and of valuable ecosystem services (including coastal protection) may occur (Chapters 3, 4 and 6). On the Pacific coast (West Coast region), anadromous fish species, such as salmon, may be particularly impacted by the combined effects of increased water temperature and lower river-water levels, affecting both survival and reproductive success (Chapter 6). In all regions, increasing ocean acidity threatens shellfish and other marine organisms, and has the potential to disrupt food chains and impact fisheries, including aquaculture operations (Chapters 4, 5 and 6).

Some ecosystem impacts have direct implications for the livelihoods and cultural well-being of Canada's coastal Indigenous populations (Chapters 4, 5 and 6). These impacts include changes in the distributions of key food species (e.g., salmon and seal) and the ability to access these resources. For example, First Nations commercial fisheries in coastal British Columbia tend to use much smaller boats than those of large-scale commercial operations, thus limiting their range and the ability of First Nations fishers to adapt to climate-related changes in species distribution (Chapter 6). In the North Coast region, changes in sea ice can greatly affect the safety of travel across the ice surface and the ability to access traditional foods (Chapter 5).

While virtually all economic sectors in Canada's coastal regions will be either directly or indirectly impacted by changing climate, the fisheries, tourism, transportation, energy and infrastructure sectors stand out as being particularly climate sensitive (Table 1; Chapters 3, 4, 5 and 6). Although available studies tend to focus on economic risks, there is also recognition of potential benefits, such as longer tourism seasons associated with warmer temperatures (Chapters 3 and 4), and new opportunities for northern shipping and natural-resource development with the reduction in sea-ice cover (Chapter 5). Risks are numerous and generally associated with impacts on the resource base (e.g., fish, forests), infrastructure and supply chains (Chapters 3, 4, 5 and 6). These risks vary regionally and locally.

Climate change, along with globalization, demographic changes and many other factors, ensure that Canada's coasts of today are not the coasts of tomorrow. Even without climate change, coasts are dynamic and always evolving. Rates of change are expected to increase in the future. Understanding the nature of the changes, including the interactions among the various drivers of change, and factoring them into planning decisions are necessary to the development of resilient economies and communities.

**TABLE 1:** Examples of positive (+) and negative (-) impacts on sectors associated with changing climate.

Fisheries	Region
Shifts in distribution will have both negative and positive implications for the species available to fish and the timing of fishing seasons. (+/-)	East, North and West
Commercially valuable shellfish fisheries, including aquaculture, are vulnerable to acidification, increases in exotic-species invasions associated with warming waters and closures from biological contamination. (-)	East and West
Extreme events, sea-level rise, storm surges and accelerated erosion will impact coastal infrastructure used for fisheries, such as ports, wharves, piers and fish plants. (-)	East, North and West
Reductions in dissolved oxygen and resulting hypoxia can result in fish kills, altered physiological development and growth and migration patterns, loss of habitat for bottom-dwelling fishes and other benthic fauna, and habitat compression. (-)	East and West
Climate change alters the health, availability and migration timing of species utilized for subsistence and commercial fisheries. (+/-)	North, East and West
Tourism	Region
With reduced sea ice in the north, there will be more opportunities for cruise-ship tourism. (+) Associated concerns relate to safety, pollution and culture. (-)	North
Warmer weather will bring longer seasons for tourist visits and summer recreational activities (+) but may reduce cold-weather recreational opportunities. (-)	East, West and North
Tourism infrastructure (e.g., wharves and coastal properties) and cultural resources (e.g., Haida Gwaii and Fortress of Louisburg) are threatened by sea-level rise and more extreme weather. (-)	East, West and North
Increases in algal blooms and decreases in water quality associated with warmer waters may make beaches less attractive. (-)	East
Infrastructure	Region
Existing infrastructure may become less usable with higher mean sea levels leading to higher tides and storm surges, and/or accelerated erosion through increased wave action and/or thermal effects on permafrost coasts. (-)	North, East and West
The highest potential for infrastructure damage in British Columbia will result from the effect that sea-level rise has on increasing the impact of high-water levels and waves during storms. (-)	West
Flooding resulting from storm surges, extreme precipitation events and storms superposed on rising sea levels will cause costly infrastructure damage. (-)	East, West and some parts of the North
Transportation	Region
Reduced sea ice and deeper waters in many harbours present potential opportunities for shipping, although ice risks remain significant. (+/-)	North and East
Flooding of highways by storm surges and storm waves can cause isolation of coastal communities. (-)	East and West
Risk of flooding of low-lying airports may increase as a result of sea-level rise and storm surges. (-)	West
Ferry services can be disrupted due to extreme-weather delays and cancellations, as well as damage from storms (to the wharves or roads that access the ferry terminals). (-)	West and East
Warmer winters lead to increased incidence of fog affecting coastal airports. (-)	North and East
Safety risks for travel across sea ice will increase. (-)	North
Energy	Region
Increased opportunity for oil-and-gas exploration and development associated with reduced sea ice and a longer navigable season. (+)	North
Sea-level rise and storms could affect existing and proposed coastal export terminals and create hazardous conditions for shipping. (-)	East and West
Ice storms and severe winds increase the risk of damage to energy-transmission infrastructure. (-)	North, East and West
Changes in streamflow patterns would affect hydroelectricity production. (+/-)	North, East and West

## RECENT EXTREME-WEATHER EVENTS DEMONSTRATE THE VULNERABILITY OF COASTAL INFRASTRUCTURE.

While climate change is a gradual process, many of the most significant impacts of climate change will relate to damages caused by extreme events. Although it is difficult to attribute specific extreme-weather events to climate change (Chapter 7, FAQ 4), it is evident that changing climate is affecting the probability of some climate extremes (Chapter 2; IPCC, 2013). The impacts associated with recent extreme events (Table 2) highlight vulnerabilities of coastal communities and infrastructure. Impacts associated with storms are the most widespread concern, but other types of extremes are important in some regions. For example, drought is a concern along the southern coast of British Columbia, with important implications for water infrastructure (Chapter 6).

The differing climatologies of Canada's three coastal regions are reflected in the differing nature of storm events. The most severe storms in the East Coast region tend to be tropical cyclones, such as Juan in September 2003 and Igor in September 2010, or nor'easters, such as 'White Juan' in February 2004 and the storm of January 2000 (Chapters 2, 3 and 4). In the West Coast region, extreme rainfall events are associated with 'atmospheric rivers' (colloquially referred to as the 'Pineapple Express'), a phenomenon in which a concentrated flow of very moist air from the tropics is transported to the coast (Chapters 2 and 6). These events often cause severe flooding, landslides and sediment loading in drinking-water reservoirs (Chapter 6). Severe storms are less common in the Arctic, particularly in the western and northern areas. Storm surges are a major hazard in some areas, notably the Beaufort Sea coast (North Coast region) and the Gulf of St. Lawrence and Atlantic coast (East Coast region). Maximum storm-surge heights exceeding 1 m occur in all three coastal regions (Chapter 2).

Storm events can cause inland and coastal flooding, wind damage and coastal erosion, all of which impact coastal communities, infrastructure and ecosystems. In extreme cases, individual storm events can result in metres of shoreline erosion (Chapters 4 and 5). Inland flooding associated with post-tropical storm Igor washed out roads and bridges across

**TABLE 2:** Examples of costly extreme events in Canada's coastal regions described in the Canadian Disaster Database (Public Safety Canada, 2014). Estimated total cost is from source database and is not limited to costs along the coast. Values include the amount paid out by insurance companies and the amount, in dollars, paid out by a Province or Territory due to a specific event. Estimates that include uninsured losses and other costs may be many times greater than the values listed here (e.g., in Chapters 3 and 4).

Region	Location	Event/Date	Description / Impacts
East	Newfoundland and Labrador	Hurricane (Hurricane Igor) September 21, 2010	<ul style="list-style-type: none"> <li>▪ wind speeds in some areas exceeded 170 km/h</li> <li>▪ approximately 90 communities were isolated due to washouts and road closures, and 22 communities declared states of emergency.</li> <li>▪ 300 evacuations</li> <li>▪ one death</li> <li>▪ estimated total cost: \$51 000 000</li> </ul>
East	Halifax, NS and Charlottetown, PE	Hurricane (Hurricane Juan) September 29, 2003	<ul style="list-style-type: none"> <li>▪ a 1.63 m storm surge occurred while Hurricane Juan made landfall just south of Halifax</li> <li>▪ water levels reached 2.9 m above chart datum, the highest water level recorded to date at this location</li> <li>▪ extensive damage to buildings, docks, boardwalks and trails occurred in the Halifax region (especially the downtown waterfront)</li> <li>▪ eight deaths</li> <li>▪ estimated total cost: \$30 900 000</li> </ul>
West	Fraser Valley and Metro Vancouver, BC	Storms and severe thunderstorms January 6–8, 2009	<ul style="list-style-type: none"> <li>▪ severe rainstorm January 6 to 8</li> <li>▪ caused overland flooding, mudslides and landslides until January 31</li> <li>▪ estimated total cost: \$16 500 000</li> </ul>
East	New Brunswick	Tropical storm (post-tropical storm Arthur) July 5, 2014	<ul style="list-style-type: none"> <li>▪ heavy rain and wind gusts of up to 100 km/hr</li> <li>▪ widespread road closures</li> <li>▪ more than 140 000 power customers were affected by outages.</li> <li>▪ estimated total cost: \$12 500 000</li> </ul>
East	Nova Scotia	Winter storm ('White Juan') February 18–20, 2004	<ul style="list-style-type: none"> <li>▪ record-breaking snowfall</li> <li>▪ four-day state of emergency</li> <li>▪ nine-hour curfew in place for three nights</li> <li>▪ thousands were left without power.</li> <li>▪ estimated total cost: \$5 600 000</li> </ul>
North	Pangnirtung, NU	Flood June 8–9, 2008	<ul style="list-style-type: none"> <li>▪ flood damaged two bridges and cut residents off from essential services</li> <li>▪ estimated total cost: \$4 900 000</li> </ul>

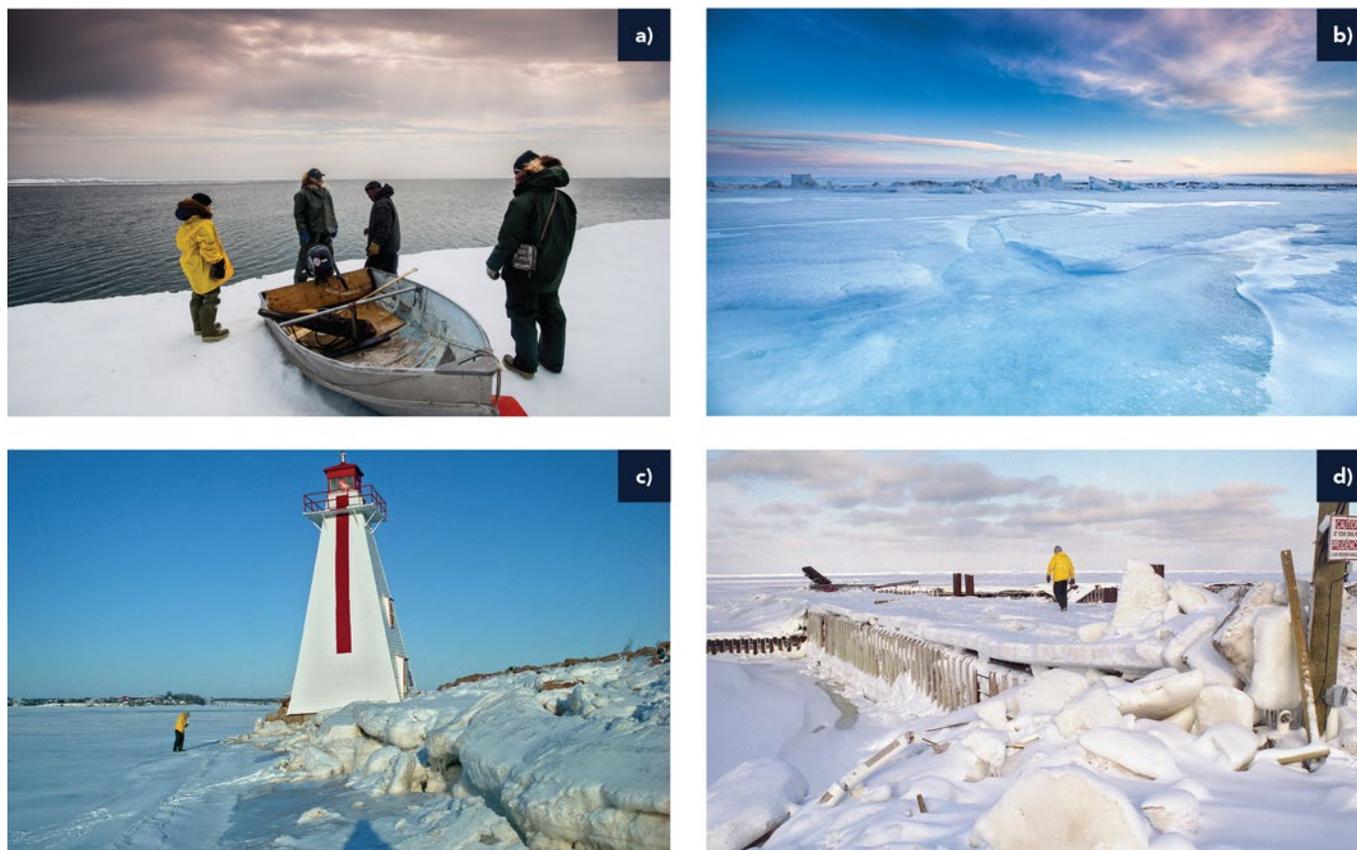
a wide swath of Newfoundland, isolating more than 150 towns (Chapter 3). An example of an ecosystem impact associated with extreme events is the 1999 storm surge in the Mackenzie Delta, which drove marine waters up to 30 km inland from the coast, resulting in the die-back of 30 000 hectares of shrub tundra and sedge wetlands (Chapter 5). Storm events that cause significant damage with high costs are more common in the East Coast region than along Canada's other coasts, as reflected in the Canadian Disaster Database (Public Safety Canada, 2014, Table 2).

### **CHANGES IN THE EXTENT, THICKNESS AND DURATION OF SEA ICE, BOTH IN THE NORTH AND IN SOME AREAS OF THE EAST COAST REGION, ARE ALREADY IMPACTING COASTS, ECOSYSTEMS, COASTAL COMMUNITIES AND TRANSPORTATION.**

Sea ice is a dominant feature along Canada's northern coasts and a seasonal feature in parts of the East Coast region. For the Arctic as a whole, the extent of sea ice in September (the minimum) has declined by about 13% per decade since the 1980s (Perovich et al., 2014). In the Canadian Arctic, decreases range from 10.4% per decade in Hudson Bay to 2.9% per decade in the Arctic Archipelago (Chapter 5). In those areas of the East Coast region that experience sea ice, the rate of decrease in average annual sea-ice cover has been 2.7% per decade since 1969 (Chapter 4).

In both regions, warmer average temperatures have resulted in delays in the date of freeze-up and advances in the timing of break-up, as well as decreases in ice thickness. At some sites in the North Coast region, the ice-free season has increased by more than 30 days during the past three decades (Chapter 5). These trends are projected to continue or accelerate in the future, with some models projecting a complete loss of summer ice cover in the Arctic before mid-century (Chapter 5). In the East Coast region, projections indicate that the Gulf of St. Lawrence will be free of winter ice by the end of this century (Chapter 4).

Changes in sea-ice cover affect coastal processes and livelihoods (Figure 2). Sea ice dampens wave action, reducing the impact of powerful storms and thereby limiting coastal erosion. However, sea ice can also negatively affect coastal stability and infrastructure. For example, a major storm in Atlantic Canada in January 2000 resulted in mobile sea ice from the Gulf of St. Lawrence being thrust onshore—an 'ice push' event—damaging shorefront buildings and harbour infrastructure,



**FIGURE 2:** Sea ice is a defining characteristic of Canada's North Coast region **a)** and **b)**, and is seasonally important in large parts of the East Coast region **c)** and **d)**, affecting both coastal processes and livelihoods. Photos courtesy of a) D.G. Clark, b) © Curtis Jones; c) and d) D. Forbes.

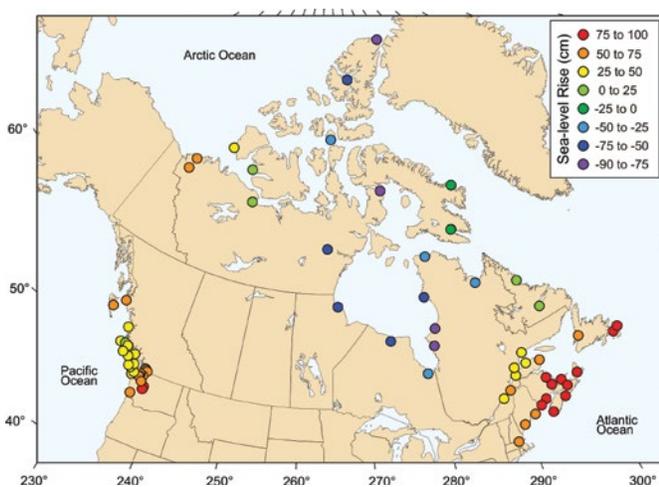
including a lighthouse in Charlottetown Harbour that was knocked off its foundation (Chapter 2). As the extent and seasonal duration of sea ice diminishes, seasonal fetches increase, resulting in larger waves and increased wave energy reaching the coast, leading to increased erosion and risk of flooding (Chapters 2, 4 and 5). In the North Coast region, the greatest increase in fetch is occurring during the fall, which is also often the stormiest period of the year (Chapters 2 and 5).

Changing ice regimes have a direct impact on the livelihoods of Indigenous peoples in the North Coast region. Less predictable weather and ice conditions make travel across the surface of sea ice more dangerous, compromising traditional harvesting activities and, in turn, negatively affecting health and well-being. For example, during the particularly warm winter of 2009–2010, half of the residents surveyed in Nain, NL noted that they could not use typical travel routes, while three-quarters reported being unable to predict ice conditions and being afraid to use the ice (Chapter 5).

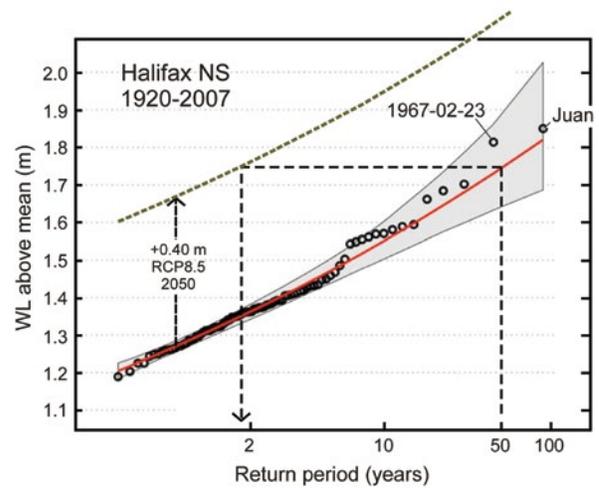
**SEA-LEVEL CHANGES WILL VARY SIGNIFICANTLY ACROSS CANADA THIS CENTURY AND BEYOND. WHERE SEA LEVEL IS RISING, THE FREQUENCY AND MAGNITUDE OF STORM-SURGE FLOODING WILL INCREASE IN THE FUTURE.**

During the current century, global mean sea level is likely to rise between 28 and 98 cm, and increases of more than 1 m are possible (Church et al., 2013). The actual amount of sea-level change experienced at any site will differ from the global average due to a number of factors, with vertical land motion caused by glacial isostatic adjustment being particularly important in Canada (Chapter 2). Because vertical motion varies greatly across Canada, projections of relative sea-level changes by 2100 range from a rise of almost 100 cm in parts of the East and West coast regions to a sea-level fall of almost 100 cm in parts of the central North Coast region (Figure 3).

In areas experiencing sea-level rise, including most of the East and West Coast regions and the Beaufort Sea coast of the North Coast region, its influence on coastal change will increase continuously throughout this century. Rising sea levels will threaten the viability of some low-lying communities (e.g., Tuktoyaktuk, NT) and increase the risk of flooding and inundation of others. For example, 40 cm of sea-level rise in Halifax by 2050 will result in extreme water levels that currently have a recurrence interval of 50 years having a much shorter recurrence interval of less than 2 years (Figure 4; Chapter 2). Coastal stability may be greater in areas of the North Coast region where sea level is falling; however, other climate change impacts, such as changes in sea-ice cover and associated increases in wave energy, will still impact these coasts (Chapter 2).



**FIGURE 3:** Projected relative sea-level change (cm) at 2100 for the median of a high-emissions scenario (RCP8.5) for coastal locations in Canada and the northern United States. See Chapter 2 for information on methodology and the climate change scenarios used in this report. Graphs showing projected change in sea level through this century for each of the Canadian sites shown in this figure are found in the relevant regional chapter (Chapter 4, 5 or 6).



**FIGURE 4:** Annual maximum hourly water levels (metres above mean) in Halifax Harbour, NS, 1920–2007, and associated return periods in years. The red line is the best fit to the observations, indicating the average recurrence interval for any given annual maximum water level today and the change in return period that results from a rise in mean sea level under a high-emissions scenario by 2050 (modified from Forbes et al., 2009; Chapter 2).

While no single value of sea-level change is meaningful for planning purposes across the whole of Canada, the strong regional and subregional patterns evident in Figure 3 allow for practical guidelines to be developed at those scales. The *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* for British Columbia is an example of this type of guidance (Chapter 6).

## **KNOWLEDGE OF CLIMATE RISKS AND THE NEED FOR ADAPTATION IN COASTAL AREAS IS INCREASING, WITH MANY EXAMPLES OF LOCAL AND REGIONAL GOVERNMENTS IN CANADA TAKING ACTION ON ADAPTATION.**

The number of studies on coastal climate change impacts, vulnerability and adaptation options in Canada has increased rapidly during the past decade. The majority of this research has focused on communities. The direct engagement of stakeholders in many of these studies has contributed to a heightened level of awareness of coastal climate hazards and the need for adaptation in each coastal region (Chapters 4, 5 and 6). As a result, it is increasingly understood that effective planning can help reduce the costs of climate impacts in the future and increase available options (Chapter 7, FAQ 11), and many communities and regions have established adaptation plans, policies and strategies (Table 3).

Adaptation is a shared responsibility, involving all levels of government, the private sector, civil society and individuals (Chapter 7, FAQ 10). All provinces and territories within Canada's coastal regions have specific adaptation strategies or plans that include reference to coastal issues. For example, the governments of Nunavut, Northwest Territories and Yukon have a Pan-Territorial Adaptation Strategy and Partnership that highlights the importance of planning for coastal erosion, and provides a mechanism for sharing knowledge and developing collaborative activities across much of the North Coast region (Chapter 5). Several provinces have developed policies, guidance and tools to inform coastal adaptation planning and practices. One of the earliest Canadian examples of planning for coastal change is the *New Brunswick Coastal Areas Protection Policy*, which was developed in 2002 to help protect public safety, infrastructure, agricultural lands and the biodiversity of plant and wildlife within the region (Chapter 4). As implementing such strategies can be challenging, there may be value in including interim measures that are subject to review and adjustment, as has been done for a large stretch of the Quebec North Shore where construction in areas of high coastal risk is prohibited (Chapter 4). In British Columbia, the government developed a sea-level rise primer and guidelines that have influenced coastal management at the community scale, including in Vancouver (Chapter 6). An important aspect of the BC guidelines is that they have a provision to be adjusted in the future, in light of new scientific results on global sea-level projections.

At the community level, there are many different examples of ongoing adaptation planning in all three coastal regions (Chapters 4, 5 and 6), which often involve other levels of government and nongovernment partners. In the North Coast region, for example, there has been an emphasis on adapting construction and design guidelines to better address permafrost degradation (Chapter 5). In the East and West Coast regions, more attention is being paid to restrictive zoning, including the use of vertical and horizontal setbacks, to reduce vulnerability to sea-level rise and coastal flooding in communities of all sizes. Examples include the City of Vancouver, which in 2013 became the first city in British Columbia to adopt formal consideration of 1 m of sea-level rise in development and planning requirements, consistent with provincial guidelines (Chapter 6); and Beaubassin-Est, NB (population 6200), which introduced a bylaw in 2011 requiring that the minimum ground-floor elevation of any new building be at least 1.43 m above the current once-in-100-years flood mark to account for anticipated sea-level rise (Chapter 4). These efforts to advance adaptation are occurring following a decade or more of rapid expansion of residential and other forms of 'ribbon' development along many coasts, which has increased both exposure and vulnerability to coastal hazards (Chapters 3 and 4).

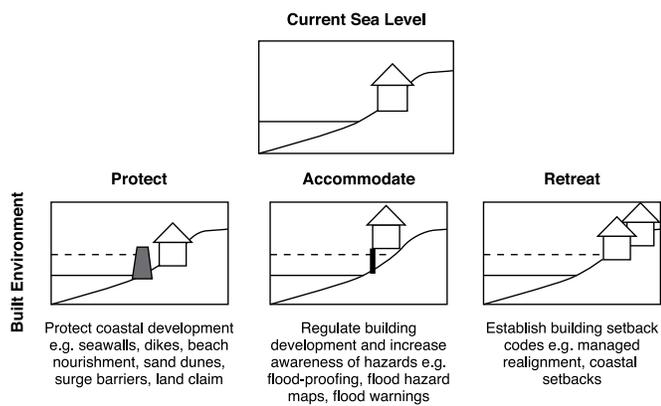
Sea level has been changing continuously along most Canadian coasts for thousands of years. These changes are related primarily to the fact that, during the last glaciation of North America, the mass of the ice sheets (up to about 4 km thick) depressed the Earth's crust beneath them and displaced viscous material in the mantle (which lies between the Earth's core and its crust). Melting of the ice sheets between about 21 000 and 8 000 years ago resulted in mantle material slowly flowing back and the Earth's crust slowly rebounding. These changes in the elevation of the Earth's crust, which are still ongoing, are known as glacial isostatic adjustment (Chapter 2). They have resulted in crustal uplift in areas near the centre of former ice sheets—along Hudson Bay, for example, where sea level has fallen by more than 200 m in the past 8 000 years and the land is presently rising at 10 mm/year or more. In contrast, sites near or beyond the margin of the former ice sheets have experienced sea-level rise during the same time period and are presently subsiding at low rates—Halifax, for example, is sinking at about 1 mm/year.

**TABLE 3:** Examples of regional and community-level adaptation programs, plans, policies and strategies.

East Coast region	Focus
The Atlantic Climate Adaptation Solutions Association is a partnership among the governments of New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador that is working with the Government of Canada to assist Atlantic Canadians to adapt to climate change.	Information and decision-support tools for all climate risks
The Municipality of Les Îles-de-la-Madeleine has a master plan in which it identifies 23 areas where erosion is an issue and where action is deemed necessary.	Coastal erosion
The Municipal Planning Strategy and Land Use By-Law for the downtown Halifax waterfront area prescribes minimum elevation for any ground-floor development.	Sea-level rise and flooding
The New Brunswick Coastal Areas Protection Policy identifies sensitive coastal features, allowing these to continue to function naturally and maintain their buffering capacity, and identifies a limited-activity and -development buffer.	Shoreline protection
Ouranos, a joint initiative of the Government of Québec, Hydro-Québec and Environment Canada, is a consortium focused on regional climatology and adaptation to climate change.	Research and decision-support tools for all climate risks
North Coast region	Focus
The Pan-Territorial Adaptation Strategy (Governments of Nunavut, Northwest Territories and Yukon) is a mechanism for the governments to work together on climate change, with a focus on practical adaptation measures.	Building capacity and enhancing action
The Nunavut Climate Change Partnership piloted the development of adaptation-action plans in seven communities (Clyde River, Hall Beach, Iqaluit, Arviat, Whale Cove, Cambridge Bay and Kugluktuk).	Permafrost, sea-level change, coastal erosion, fresh water
Several coastal communities in Nunavik participated in a permafrost-monitoring and -mapping project to inform future development and land-use planning.	Permafrost degradation
SakKijânginnatuk Nunalik: The Sustainable Communities Initiative in Nunatsiavut addresses issues that are central to community well-being and sustainability in the context of a changing climate.	Informing best practices
West Coast region	Focus
British Columbia provincial guidelines for development in flood-risk areas identify the need for Flood Construction Levels in line with the increased risk presented by sea-level rise.	Sea-level rise
The Capital Regional District Climate Action Program is working with the public, private and nonprofit sectors to reduce vulnerability to sea-level rise.	Sea-level rise
The City of Vancouver is in the process of implementing their adaptation plan (which was initiated in 2007 through the passing of a city motion), which includes the adoption of formal consideration of 1 m of sea-level rise in development and planning requirements.	Sea-level rise
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.	Species shifts and sea-level rise
The Town of Qualicum Beach is in the planning phase of a comprehensive Waterfront Master Plan that will include planning for adaptation to sea-level rise.	Sea-level rise

**A RANGE OF ADAPTATION MEASURES WILL BE NEEDED IN MOST SETTINGS. ALTERNATIVES TO HARD COASTAL-PROTECTION STRUCTURES CAN BE EFFECTIVE IN ADDRESSING COASTAL EROSION AND FLOODING IN MANY AREAS.**

In Canada and elsewhere, there has been a tendency to favour hard-armouring protection measures, such as seawalls, bulkheads and dikes, to address issues of sea-level rise, coastal erosion and flooding (Chapters 3, 4 and 6). While hard armouring may be the most viable option in some areas, alternatives such as soft-armouring measures, accommodation and retreat/avoidance (Figure 5) may be more efficient, less costly and more sustainable responses in many situations (Chapter 3; Chapter 7, FAQ 11). Hard-armouring protection, if not properly designed, placed and maintained, can result in maladaptation by increasing impacts in adjacent areas and by contributing to the loss of key ecosystem services. For these reasons, the use of hard-protection measures is restricted in some areas (Chapter 4).



**FIGURE 5:** Schematic representation of protection, accommodation and avoidance/retreat as options for coastal adaptation (modified from Linham and Nichols, 2010, based on IPCC, 1990)

occasional short-term impacts (e.g., impacts from storm events or seasonal flooding) while people continue to occupy and/or use the coastal area. Examples include elevating buildings and ensuring alternative transportation links. Retreat can have considerable economic and social costs, and is generally one of the last options considered. However, managed retreat, which involves planned abandonment and gradual relocation of assets based on understanding of future changes in climate risk, can be prudent. Avoidance through proactive planning may be the most effective means of reducing risk. Harbour and waterfront plans for Gibsons, BC, Charlottetown, PE and Halifax, NS all have provisions for new development that factor in sea-level rise and increased storm-surge flooding, including avoidance of low-lying areas (Chapter 3).

Most adaptation plans that address sea-level rise, coastal flooding and erosion will include elements of all of these approaches (Chapter 3). For example, although coastal erosion represents a major risk to the Îles-de-la-Madeleine, QC, the decision was made to leave 95% of the islands unprotected from natural processes in order to preserve the natural beauty of the archipelago, which is a primary draw for tourists. This will require planned retreat and relocation of some structures. Hard- and soft-armouring measures will be utilized to protect a few town centres and critical infrastructure (Chapter 4).

**IT IS IMPERATIVE THAT FUTURE DEVELOPMENT BE UNDERTAKEN WITH AN UNDERSTANDING OF THE DYNAMIC NATURE OF THE COAST AND CHANGING COASTAL RISKS. MONITORING AND ASSESSMENT OF THE EFFECTIVENESS OF ACTIONS TAKEN TO DATE, AS WELL AS RESEARCH TO FILL DATA AND KNOWLEDGE GAPS, WOULD HELP INFORM SUSTAINABLE PLANNING AND DEVELOPMENT.**

In addition to implementing adaptation measures to address current risks in coastal areas, enhancing coastal resilience requires integrating changing climate into planning of future development. Activities in coastal regions have been, and will continue to be, major economic drivers for the whole of Canada. There are proposals for major infrastructure developments in all three of Canada's coastal regions (Chapters 4, 5 and 6), many related to improving access to foreign markets. In addition, demand for residential development near the shoreline remains high in many areas (Chapters 4 and 6). The rapidly growing populations of most northern coastal communities (Chapter 5) also increase demands for residential development and other infrastructure, including storm-water drainage systems capable of handling runoff from extreme rainfall events (Chapter 4). There are many policy instruments that can be used to facilitate implementation of plans, including regulations, bylaws, zoning and protective easements, and building codes.

Planning for sea-level change needs to take into account the variability across Canada, the timeframe of interest and the importance of extreme water levels. For planning horizons of less than about 35 years, the amount of sea-level change at a given location is similar under all climate change scenarios, thereby reducing uncertainty. In the latter half of the century, the choice of scenarios becomes more important and therefore should be undertaken with an understanding of risk tolerance (Chapter 3). Projections of future extreme water levels, which are particularly critical for planning future infrastructure, need to consider not only sea-level changes and storms, but also natural oceanographic variability (e.g., El Nino/Southern Oscillation in the West Coast region that can raise local sea level by tens of centimetres) and other factors, such as wave set-up and run-up. For example, a major storm in January 2000 produced extreme waves that caused severe damage as high as 18 m above mean sea level in southwestern Newfoundland (Chapter 2). Ongoing integrative analysis is helping to map the sensitivity of coasts to sea-level change and other climate-related changes (Box 3) and could be complemented by additional analysis to more fully capture the human dimension of coastal vulnerability.

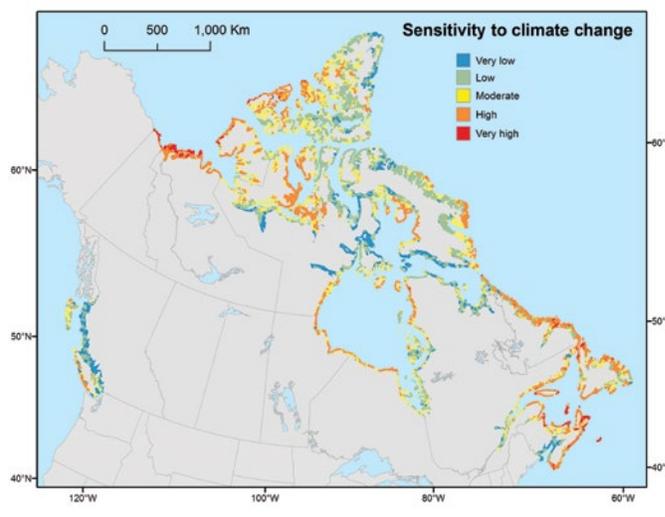
Soft-armouring measures include maintaining and/or restoring beaches, marshes and coastal vegetation, all of which can lessen the damaging effects of tides, currents, waves and storms (Chapter 3). There are many examples from the West Coast region, several of which are affiliated with the Green Shores program (Chapter 6). Examples from the East Coast region include restoration of salt marshes and the use of clean dredged sand to replenish protective beaches (Chapter 4). While soft-armouring measures have been demonstrated to be cost effective and environmentally beneficial, the fact that these measures are largely invisible, and therefore poorly understood by the general public, may present a barrier to their use (Chapter 4).

Accommodation responses are designed to lower the risk associated with various natural hazards. They allow for

### BOX 3

## CANCOAST: A TOOL FOR ASSESSING COASTAL SENSITIVITY

Building on mapping of coastal sensitivity to sea-level rise (Shaw et al., 1998), ongoing work has developed an extensive database to help map sensitivity to inundation, coastal flooding and erosion arising from climate-related changes in sea level, sea ice and storminess along all of Canada's marine coasts (Figure 6). The CanCoast database contains digital-elevation data, projections of sea-level change for 2050, ground-ice conditions for coastal permafrost areas, and information on surficial materials, landforms, tidal range, wave height and recent trends in sea-ice concentrations. Potential applications for CanCoast include hazard mapping and impact assessment, adaptation planning, and analysis of data and knowledge gaps.



**FIGURE 6:** Preliminary map of coastal sensitivity to climate change in Canada, developed using the CanCoast database (Chapter 2). Note that some highly sensitive areas (e.g., the Fraser River delta) are not clearly visible at the resolution shown here.

A major need in Canada, and elsewhere, is improved monitoring and evaluation of adaptation measures that have been implemented in order to promote shared learning and identify best practices. Although all the regional chapters of this report include examples of adaptation actions taken at the local and regional scale, none of these have been thoroughly assessed in terms of their effectiveness in reducing climate risks. Additional research and enhanced collaboration related to collection and sharing of data could help address existing spatial gaps in understanding of climate vulnerability, including at the local level (Chapters 4, 5 and 6). Such research could strengthen the business case for adaptation by providing quantitative analyses of the costs and benefits associated with adaptation measures (Chapter 7, FAQ 11).

## CONCLUSION

All of Canada's coastal regions are being impacted by changing climate, and these impacts will continue to increase in the future. The resulting risks and opportunities vary within and between regions, reflecting differences in both human and natural systems and in climate sensitivity. Key climate-related impacts emphasized in this report include changes in sea level, sea-ice extent, coastal flooding and ecosystem services. As a highly developed nation, Canada possesses the capacity needed to adapt to these impacts, but adapting in an efficient and proactive manner requires planning that accounts for the changing nature of climate risks. Limited site-specific knowledge and capacity to respond can be barriers to adaptation at the local scale, which may be best addressed through further collaboration between levels of government, as well as with academia and other nongovernment players. Collaboration and innovation are essential for achieving a vision of a sustainable and resilient coastal Canada.

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