CHAPTER 7: FREQUENTLY ASKED QUESTIONS

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EDITORS' NOTE

This chapter presents a series of frequently asked questions (FAQs) relevant to understanding climate change impacts and adaptation in Canada's coastal regions. It is clear from the regional chapters that climate is changing, with coastal regions experiencing changes in air and water temperatures, precipitation patterns, storms, sea level and sea-ice cover. The impacts of these changes on ecosystems, communities and sectors will differ within and between regions due to a number of factors, such as the nature of the coastline, the presence of natural and built protection (e.g., beaches, marshes, seawalls, dikes and breakwaters) and the capacity to adapt.

These FAQs are intended to provide concise answers to questions decision makers are asking to better understand the implications of climate change for Canada's coastal regions. They are not comprehensive, nor do they provide detailed explanations. Instead, they focus on highlighting relevant examples and encouraging readers to consult the full chapters of *Canada's Marine Coasts in a Changing Climate*, as well as the resources listed in FAQ 12, for more information.

FAQ 1: WHAT IS A COASTAL ASSESSMENT, AND WHY AND HOW WAS THIS REPORT PRODUCED?

Author: Fiona J. Warren *(Natural Resources Canada)*

Science assessments are syntheses of existing information, developed to present the state of knowledge on specific issues. This coastal assessment, *Canada's Marine Coasts in a Changing Climate*, focuses on climate change impacts and adaptation in Canada's marine coastal regions. Considering both the natural and built environments, the report aims to provide answers to questions such as "How is the climate changing in coastal regions?"; "How are these changes affecting the physical coastline, communities, ecosystems and economic sectors?"; and "How are Canadians adapting to these changes to reduce risks or take advantage of potential opportunities?"

Assessment reports aim to be relevant to policy issues (i.e., to address issues of concern to decision makers) but not be policy prescriptive. Therefore, this assessment does not provide policy recommendations or prescribe specific actions, but rather serves as a knowledge foundation to inform decisions. Previous science assessments that complement this report include the Canadian publications *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (2014) and *From Impacts to Adaptation: Canada in a Changing Climate* (2008; Figure 1), as well as international reports such as those of the Intergovernmental Panel on Climate Change (IPCC).

In this report, *Canada's Marine Coasts in a Changing Climate*, the main chapters present regional (East, North and West) perspectives. In these chapters, the authors introduce the regions and then discuss observed and projected changes in climate, as well as climate risks, opportunities and adaptation approaches. Supporting chapters—'Dynamic Coasts in a Changing Climate' (Chapter 2) and 'The Coastal Challenge' (Chapter 3)—provide the context for the regional discussions by presenting national-scale overviews on issues such as the diversity of marine coasts, sea-level change and approaches to adaptation. In all cases, the chapter content reflects the availability and accessibility of information, while the expert judgement of the author teams brings added value to the summary of existing knowledge.

The main goal of the report is to provide an up-to-date, reliable source of information that informs decision-making, planning and policy development by:

- describing the current state of knowledge relevant to understanding how climate change presently impacts, and will continue to impact, the natural and built environment in Canada's marine coastal regions; and
- consolidating information relevant to adaptation decision making in coastal areas, including experience with practical adaptation measures.

Developing the coastal assessment involved contributions from a team of editors, 12 lead authors and 44 contributing authors. The work was overseen by a 14-person Advisory Committee that included multidisciplinary experts and practitioners from the federal, provincial and territorial governments, academia and the private sector. This

FIGURE 1: Recent Canadian science assessments on climate change impacts and adaptation.

committee was engaged throughout the assessment process, including the initial planning to help ensure that the report addressed the right questions and was organized in a manner would meet the information needs of decision makers. During the writing process, the authors gathered, assessed and synthesized information from academic journals, reports, presentations and local/practitioner knowledge to produce draft chapters. Edited drafts were reviewed by experts in the field (74 in total for report). The more than 2 500 comments received through this review process were then used by the chapter authors to develop their final drafts.

FAQ 2: WHAT IS ADAPTATION TO CLIMATE CHANGE AND HOW DOES IT RELATE TO CLIMATE CHANGE MITIGATION?

Author: Fiona J. Warren (*Natural Resources Canada*)

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2012). It involves making changes in our activities and decisions to reduce the harm from negative impacts of climate change and take advantage of any positive impacts. As such, adaptation is a broad concept that encompasses a wide range of possible actions. It can be as simple as installing shut-off valves in homes to reduce the risk of sewer backup causing basement flooding during heavy rainfall events, or as complex as planning and implementing a shoreline-protection strategy to reduce the risks of flooding due to sea-level rise. Regardless of the scale, adaptation is undertaken to help ensure that our lives, our communities and our economy are better prepared for climate change, both now and in the future.

Although adaptation can be undertaken spontaneously in response to specific events such as extreme weather, this report, *Canada's Marine Coasts in a Changing Climate*, focuses on planned adaptation, which includes modifying operations, introducing new technologies, changing planning guidelines and approaches, and revising investment practices, regulations and legislation. These changes often require careful planning and collaboration that are guided by both scientific research and a strong understanding of the systems involved. They are also affected by local capacity and resource availability. Many of the adaptation approaches discussed in the report involve dealing with sea-level rise and include actions to reduce the risks of flooding. However, adaptation in coastal regions also involves managing other impacts, such as warmer temperatures, shifting precipitation patterns, reduced sea ice and changes in inland hydrology (e.g., river flows), as well as addressing the risks of extreme weather events such as hurricanes and other major storms.

> Without careful planning, the risk of *maladaptation* increases. Maladaptation refers to actions that serve to increase, rather than reduce, vulnerability.

Adaptation is a necessary complement to reducing greenhouse gas emissions (mitigation) in responding to climate change. Mitigation actions decrease the amount of greenhouse gases entering the atmosphere in two ways. The first is by reducing emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases, and the second is by enhancing greenhouse gas sinks, such as forests and wetlands. Mitigation reduces both the magnitude and the rate of climate change. For example, scenarios considered by the IPCC in its latest assessment report suggest that, for the period 2081–2100, average global surface temperature could increase by less than 2°C above pre-industrial levels with very aggressive mitigation measures but by more than 4.5°C above pre-industrial levels with only very limited mitigation effort. For the same scenarios, the likely range of global sea-level rise is 26–82 cm for the period 2081–2100. Therefore, the extent and amount of adaptation needed depends on the success of mitigation efforts. Without efforts to reduce greenhouse gas emissions, some natural and managed systems would be overwhelmed and unable to adapt successfully. Strong and successful mitigation measures will provide more time to plan and implement adaptation, as changes will occur more gradually and be less extreme.

There can be co-benefits, or synergies, between these two responses to climate change, where actions taken to adapt also serve to reduce greenhouse gas emissions, or mitigation actions also reduce vulnerability to climate change (Figure 2). For example, green roofs, where vegetation is planted and maintained on the roofs of buildings, have both adaptive benefits (e.g., moderated storm-water runoff, reduced urban-heat-island effect and improved air quality) and mitigative value (e.g., reduced energy consumption, reduced greenhouse gas emissions and increased carbon dioxide absorption). However, there is also the potential for conflict between adaptation and mitigation, where adaptation choices can increase greenhouse gas emissions. Use of air conditioners to deal with higher temperatures, for example, is associated with increased energy use and related emissions. These examples highlight the need for co-ordinated policy responses.

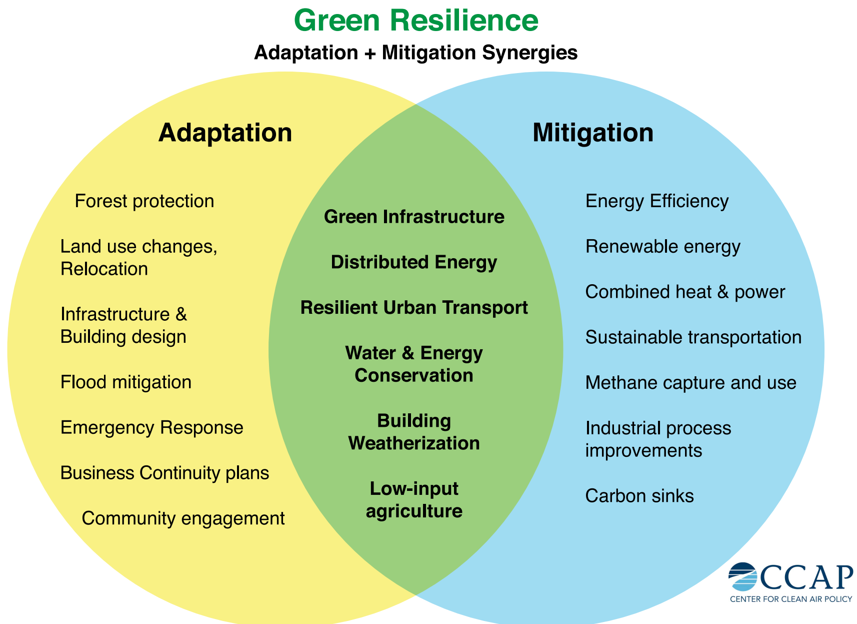

FIGURE 2: Examples of adaptation, mitigation and overlap between the two approaches. *Image courtesy of Center for Clean Air Policy, 2016.*

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FAQ 3: WHAT IS THE DIFFERENCE BETWEEN CLIMATE CHANGE AND CHANGING WEATHER?

Author: Kevin Anderson *(Environment Canada)*

Weather refers to the state of the atmosphere at a given time. For instance, at some time on a given day in Halifax, it may be 20°C and sunny with winds blowing from the east. But those conditions probably won't be the same 12 hours later or 6 months down the road. The weather changes constantly—during the course of a day and from season to season. This is a normal consequence of the continually changing state of the atmosphere and ocean.

Climate can be thought of as the 'average weather'. More rigorously, it can be defined as the statistical description of weather, including the mean and variability, over a period of time ranging from seasons to decades to thousands of years. When two distinct areas experience different average weather conditions over the long-term, we say that they have different climates. For example, most of Australia does not usually get snow and its summers can be very hot. Those conditions are quite different from the weather we generally experience in Canada, so we say that Canada has a different climate than Australia. Even within Canada, we can say that Toronto has a different climate than Vancouver (because of the generally drier summer and much wetter and milder winter in Vancouver) even though, at a particular time, these two cities may experience similar weather.

The Earth's climate varies from season to season and from year to year. For example, some winters are colder and have more snow than others, while some summers are warmer and drier than others. This is called natural climate variability and it happens on a global, regional and local scale. On top of this natural climate variability, however, the overall climate system of the Earth has been changing due to increased levels of greenhouse gases that are emitted into the atmosphere.

The increase in global average temperature (known as 'global warming'; Figure 3) is only one indicator of how much the Earth's climate is changing. There are also many other changes associated with this warming climate, such as changing precipitation patterns, widespread melting of snow and ice, thawing of permafrost and increasing frequency of some severe weather around the world (IPCC, 2013). To understand how climate is changing, scientists look at the total change over a given time period (e.g., over time scales ranging from decades to centuries and beyond), as well as how each climate-system indicator (e.g., temperature, rain, snow) changes on a seasonal or yearly basis within that longer time period.

As climate changes, so does the general weather. This means that we may experience different average weather conditions than what we were used to in the past. For example, what we think of today as a very cold winter day in different parts of Canada is generally not as cold and/or as frequent as it used to be 50 years ago. This is due to the increase in winter temperature.

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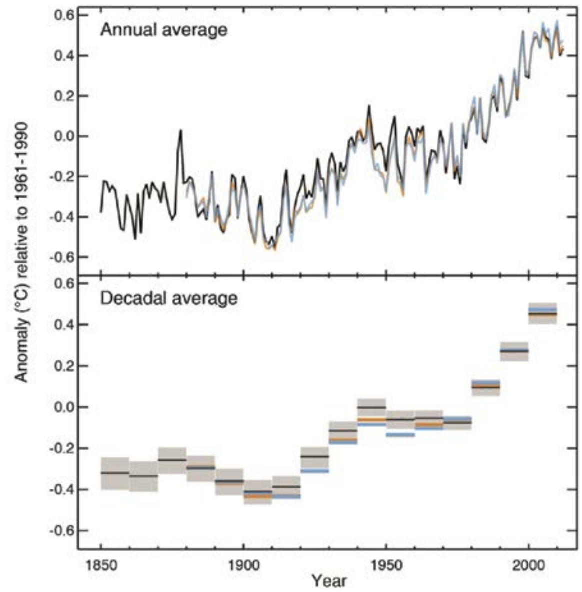

FIGURE 3: Observed, globally averaged, combined land and ocean-surface temperature anomalies, 1850–2012 (IPCC, 2013).

FAQ 4: CAN RECENT EXTREME EVENTS OBSERVED IN COASTAL REGIONS BE ATTRIBUTED TO CLIMATE CHANGE?

Author: Kevin Anderson *(Environment Canada)*

A changing climate can be expected to lead to changes in climate and weather extremes. For example, the Intergovernmental Panel on Climate Change (IPCC, 2013) noted that the number of warm days and nights, and the frequency of heat waves in certain parts of the world (large parts of Europe, Asia and Australia) have increased since about 1950 and that the number of heavy precipitation events over land has increased in more regions than it has decreased. However, it is challenging to associate a single extreme event with a specific cause (such as increasing greenhouse gases) because a wide range of extreme events could occur even in an unchanged climate, and because extreme events are usually caused by a combination of factors. As of the publication of this report, observed extreme events in Canadian coastal regions have not been attributed to a particular cause. Despite this, it may be possible to make an attribution statement about a specific weather event by analyzing how a particular cause may have changed the probability of the event's occurrence or its magnitude.

Attribution of extreme events to causes is an active area of research in the scientific community around the world. On the global scale, many events have been studied with the rigour required to determine whether or not there was a human influence (Herring et al., 2014). Studies show clear evidence for human influence on some events and little evidence for human influence on others. For example, human influence may have at least doubled the odds of the 2003 European heat wave (Stott et al., 2004); and, while natural climate variability is capable of producing the magnitude of the 2010 Russian heat wave, the odds of that heatwave occurring were significantly increased due to human influence (Otto et al., 2012).

Studies on Canadian extreme weather events have been focused on the broad scale. For example, changes in certain extremes have been confidently observed in many parts of Canada: the number of hot days and nights has increased, while cold extremes (e.g., the number of cold days and nights) have decreased (Wang et al., 2013). With respect to coastal extremes in Canada, research shows that extreme North Atlantic surface-wave heights have increased in the high latitudes (e.g., Newfoundland coast and north) but decreased in the mid-latitudes (Wang et al., 2009). This trend contains a detectable response to anthropogenic (e.g., greenhouse gases) and natural (e.g., volcanic eruption) influences combined. These changes are consistent with expected changes due to increases in atmospheric greenhouse gases.

Looking toward the future, climate change is projected to affect both the intensity and the frequency of many types of extreme events. State-of-the-art climate models project an increase in hot extremes, a decrease in cold extremes and an intensification of the global hydrological cycle that will lead to more concentrated episodes of rain/snow and longer dry periods in between, all of them associated with rising global temperatures due to the continued increase of greenhouse gases in the atmosphere. This is the basis for expecting changes in extreme events such as heat waves, heavy precipitation and drought.

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FAQ 5: HOW IS THE CLIMATE GOING TO CHANGE IN CANADA'S COASTAL REGIONS AND HOW ARE THESE PROJECTIONS DETERMINED?

Author: Thomas James *(Natural Resources Canada)*

Understanding the risks that climate change presents to Canadian coasts requires, among other things, information regarding likely changes in climate parameters. This information can be obtained from complex computer models that simulate the Earth's climate system, building on observations of past climate variability. Output from these models is commonly discussed in terms of changes in temperature, precipitation patterns, sea-ice extent and global sea level. However, managing coastal risks also requires knowledge of other climate parameters, such as wind, waves, fog and local sea-level change (*see* Chapter 2). In general, confidence in projected climate changes is greatest for temperature, somewhat less for precipitation changes and sea level, and generally low for factors such as wind, waves and fog.

Air temperatures in Canada are projected to rise through the 21st century, with the largest increases in the winter (December to February) and in the North Coast region. Averaged across Canada and over the time period 2081–2100, winter temperatures are projected to rise from as little as 1.5–3.4° C for the low-emissions scenario (RCP2.6) to a high of 7.2–10.8° C for the high-emissions scenario (RCP8.5), relative to 1986–2005[1] (Box 1; IPCC, 2013; Environment Canada, 2015). Projected temperature increases are generally smaller for the coastlines of the East and West Coast regions than for noncoastal regions (Figure 4a, b).

Precipitation in Canada is projected to increase in most regions and seasons, with the notable exception of parts of southern Canada in summer, where little change or a decrease is projected. The largest projected percentage increases in precipitation are in the North Coast region in the winter. Here, median precipitation is projected to increase by 10–30% for the low-emissions scenario and by more than 50% in most of the region for the high-emissions scenario in 2081–2100, relative to 1986–2005 (Figure 4c, d). Larger absolute changes in precipitation (expressed in actual amounts rather than percentages) are anticipated in the East and West Coast regions, in comparison to the North Coast region.

Regional projections of ocean temperatures are less certain, but average temperatures are expected to increase in the upper kilometre of the ocean for all scenarios at all latitudes by the end of the century (Collins et al., 2013). A projected decrease in the maximum area of sea ice (Figure 4e, f; *see* Chapters 2, 4, 5) is linked to higher atmospheric and ocean-water temperatures. The time of freeze-up (onset of sea ice) is also projected to be delayed. The Arctic Ocean is projected to be essentially ice free at the time of minimum sea-ice extent (September) by mid-century (IPCC, 2013).

1 Ranges are derived from the 25th and 75th percentiles.

BOX 1
CLIMATE MODELS AND SCENARIOS

Climate projections are generated from computer models of climate that are based on the fundamental physical and chemical laws governing the transfer and motion of heat (energy) and mass into, within and among the components of the climate system and evaluated against observations. While early models (General Circulation Models or GCMs) focused on the atmosphere, the global ocean also plays a key role in climate (e.g., as a repository of heat and some atmospheric constituents). Therefore, ocean circulation models were developed and coupled to GCMs to better simulate the climate system (Atmosphere-Ocean General Circulation Models or AOGCM). A modern Global Climate Model (also having the acronym GCM) is composed of an AOGCM and also considers interactions of the atmosphere with the Earth's solid surface, including soil, vegetation and the cryosphere (glaciers and ice sheets, permafrost, sea and freshwater ice, and snow). Chemical transport models may also be coupled to a global climate model to better track, for example, the path of anthropogenic carbon in the atmosphere and oceans, or the projected recovery of the ozone hole. Earth System Model (ESM) is a general term to describe computer models that add biochemical and geochemical processes to the coupled physical climate system and therefore allow, for example, projections of ocean acidification as part of the response of the climate system to increasing greenhouse gases.

The GCMs and ESMs use scenarios* of future atmospheric greenhouse gas concentrations to project changes in the climate system. The projections** summarized in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change were based on four Representative Concentration Pathway (RCP) scenarios (*see* Chapter 2). This is in contrast to the Fourth Assessment Report, which was based on the Special Report on Emissions Scenarios (SRES) scenarios. The projections in the Fifth Assessment Report and in this report are derived from an international comparison and synthesis of climate-model projections called the Coupled Model Intercomparison Project, Phase 5 (CMIP5). The Canadian modelling contribution to CMIP5 was provided by the second generation of the Canadian Earth System Model, CanESM2, developed by the Canadian Centre for Climate Modelling and Analysis of Environment Canada.

Environment Canada provides a web-based service, 'Canadian Climate Data and Scenarios', to give maps, plots and tables of projected temperature and precipitation changes for Canada (Environment Canada, 2015). Values include median projected values and 25th and 75th percentiles, giving an indication of the uncertainty in projections. Information is available for different time ranges, and summary statistics are available for the provinces and territories. The service can be accessed at http://ccds-dscc.ec.gc.ca/?page=main. The Fifth Assessment Report projections are available under the CMIP5 menu. A guidebook for adaptation practitioners on how to use climate projections (Charron, 2014) is available at http://www.ouranos.ca/media/publication/352_GuideCharron_ENG.pdf.

* A scenario is a "plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions." (IPCC, 2014).

** A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models (IPCC, 2014).

Associated with the projected increases in temperature, fewer cold-weather extreme events and more hot-weather extreme events are expected, although these will vary regionally. Naturally occurring climate variability and dynamics play an important role in determining extreme events. The El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are important contributors to extreme events in the West Coast region (*see* Chapters 2, 6). Projected increases in extreme ENSO events (Cai et al., 2014) may contribute to increased extreme water-level events in the West Coast region (Barnard et al., 2015). There is an expectation of increasing storminess in the future on a global scale. However, storminess at any specific location may or may not increase, depending on the position relative to storm source regions and tracks. Region-specific projections of storminess and associated storm surges have low confidence (*see* Chapter 2; IPCC, 2013).

Globally, wind speed and wave height have increased in recent decades (Young et al., 2011). In much of the Arctic, including the Beaufort Sea, wave heights are projected to increase in the future due to the combined effects of winds and reduced sea-ice concentrations (*see* Chapter 2; Khon et al., 2014). Increased wave heights in the winter are also expected in parts of the East Coast region, associated with reduced sea-ice concentrations in coming decades. Larger waves tend to have greater erosive power.

There is high confidence that projected increases in mean relative sea level (FAQ 6) and reductions in sea ice will lead to increases in the frequency and magnitude of extreme water levels (IPCC, 2013). This is expected for parts of the East Coast region and the Beaufort coastline. The West Coast region is also susceptible to increased extreme water-level events arising from projected increases in sea level.

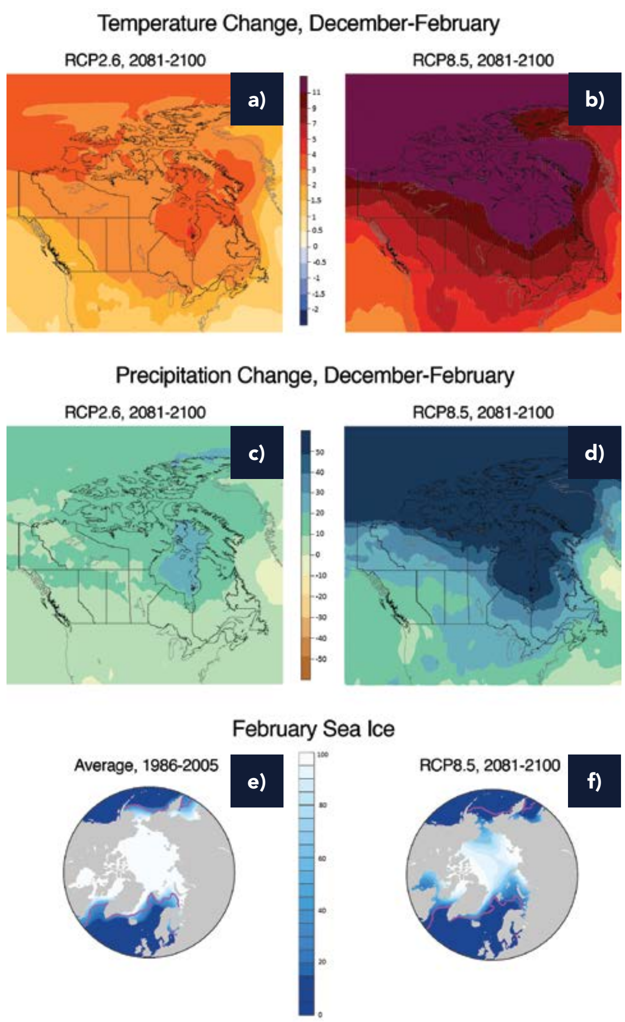

FIGURE 4: Projected median temperature changes during the winter months for the **a)** low-emissions; and **b)** high-emissions scenarios for 2081-2100, relative to 1986-2005 (IPCC, 2013; Environment Canada, 2015). Projected median precipitation changes during the winter months for the **c)** low-emissions and **d)** high-emissions scenarios for 2081-2100, relative to 1986-2005 (IPCC, 2013; Environment Canada, 2015). Observed **e)**; average for 1986–2005) and projected **f)**; high-emissions scenario for 2081–2100) February Arctic sea-ice extent (*extracted from* Collins et al., 2013, Figure 12.29). The red line is the observed 15% concentration contour for 1986–2005.

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FAQ 6: HOW WILL SEA LEVEL CHANGE IN CANADA AND HOW ARE THE PROJECTED CHANGES DETERMINED?

Author: Thomas James *(Natural Resources Canada)*

Globally, mean sea level is projected to rise by tens of centimetres, and possibly by more than a metre, by 2100 (Figure 5a; *see* Chapter 2; IPCC, 2013). The main causes of global sea-level rise are warming of the upper layer of the oceans (steric effect), and meltwater and iceberg-discharge contributions from glaciers, ice caps and grounded ice sheets. Antarctica has the potential to contribute additional tens of centimetres to sea-level rise by 2100. The magnitude and timing of this potential contribution is unknown and its occurrence unlikely (IPCC, 2013), but it may need to be considered in cases where the tolerance to risk of sea-level rise is low (*see* Chapter 3). Sea-level rise has the potential to contribute to increased coastal erosion and to increase extreme water-level events that cause coastal flooding.

Projected relative sea-level change varies regionally due a number of factors (*see* Chapter 2; Milne et al., 2009). Of these factors, vertical land motion (uplift and subsidence) has a dominant effect in Canada. Relative sea-level change is the change in water level experienced on the solid land surface. It is the combined result of changes to global (absolute) sea level and vertical land motion. Land uplift reduces projected relative sea-level rise at a location, whereas land subsidence increases projected relative sea-level rise. In cases where land-uplift rates are large, relative sea level may be projected to fall, even though global sea level is projected to rise.

The highest projected relative sea-level rise is for parts of the East Coast region (*see* Chapters 2, 4). Sea level is projected to rise elsewhere in the East Coast region, through all of the West Coast region and on the Beaufort Sea coastline of the North Coast region (Figure 5b–d; *see* Chapters 2, 4, 5, 6). In contrast, sea level is projected to fall in Hudson Bay and most of the Canadian Arctic Archipelago of the North Coast region (Figure 5b–d; *see* Chapters 2, 5), where the land is rising rapidly. For the most part, these broad-scale patterns of projected relative sea-level change reflect vertical land motion.

Throughout most of Canada, glacial isostatic adjustment (GIA, also known as postglacial rebound) is the dominant source of vertical land motion (*see* Chapter 2). Large ice sheets covered most of the Canadian land mass during the last ice age and depressed the surface of the Earth, which was accommodated by slow viscous yielding at great depths in the Earth's interior. During and following deglaciation, the depressed land surface began to rise toward its former elevation. In regions at the margins of and outside the former ice sheets, the land rose due to flow in the interior of the Earth during glaciation, and these regions are presently sinking. The Earth's interior responds on a time scale of thousands of years, and the GIA-induced vertical land motion is still occurring today, thousands of years after deglaciation.

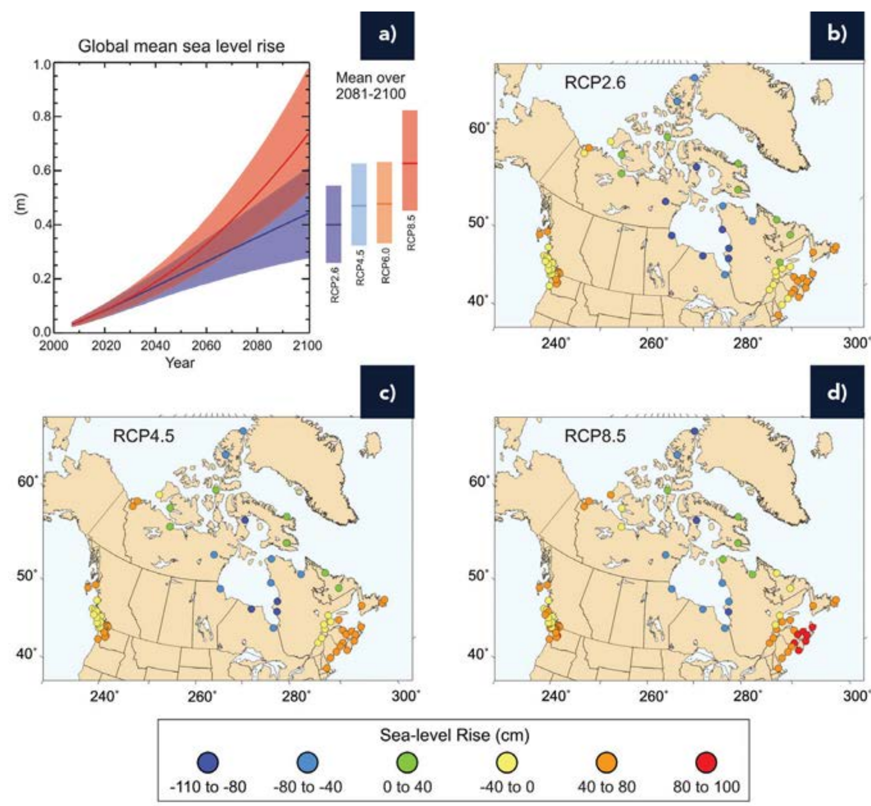

FIGURE 5: **a)** Projected global sea-level rise through the 21st century for the low-emissions (RCP2.6) and high-emissions (RCP8.5) scenarios (IPCC, 2013, Figure SPM.9). The mean projected global sea-level rise over 2081–2100 (rectangles in panel **a)** includes the projections for intermediate-emissions scenarios RCP4.5 and RCP6.0. Projected relative sea-level rise at 2100 (median values plotted here) are given for localities in Canada and the adjacent mainland United States for the **b)** low-emissions scenario, **c)** intermediate-emissions scenario (RCP4.5), and **d)** high-emissions scenario. Projections are relative to 1986–2005 and are based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Church et al., 2013a, b), modified to incorporate vertical crustal motion measured at Global Positioning System sites (James et al., 2014, 2015). The median projections and their associated 5–95% confidence intervals encompass the likely range of sea-level change, defined as having a probability of 66–100% (IPCC, 2013).

The land is rising in Hudson Bay and much of the Canadian Arctic Archipelago due to GIA. Parts of the East Coast region and the Beaufort Sea coastline of the North Coast region are sinking. Elsewhere, the land is rising but at slower rates. On the deltas of the Fraser and Mackenzie rivers, sediment consolidation is generating local subsidence, which contributes to relative sea-level rise. In the West Coast region, active tectonics arising from the interaction of the Pacific and Juan Fuca plates with the North America plate also contribute to vertical land motion.

Projected reductions in the mass of grounded ice from melting and iceberg discharge add to global mean sea level but reduce projected relative sea-level rise in the West and North Coast regions. The effect is substantial in the northeastern part of the North Coast region, which hosts the glaciers and ice caps of the Canadian Arctic Archipelago and is located near the Greenland Ice Sheet. All of these ice masses are projected to undergo major reductions in mass throughout the century. This will cause the land to rise and contribute to reductions in local sea-level rise. As well, the reduced gravitational attraction of the shrinking ice masses causes the surface of the ocean to fall. At nearly all locations, projected relative sea-level changes are greater for IPCC (2013) scenarios with larger emissions and higher rates of projected global sea-level change. An exception occurs at Alert, Nunavut, where the larger amounts of ice-mass reduction projected by the larger emissions scenarios cause greater crustal uplift and higher rates of projected sea-level fall.

The projections of mean sea level described here are the basis for considering future changes to extreme water events and their associated consequences of flooding and coastal erosion (*see* Chapters 2–6). In the short term (years to a few decades), natural climate variability and dynamics cause fluctuations in sea level that are expected to dominate extreme water events. In particular, in the West Coast region, the El Niño/Southern Oscillation and the Pacific Decadal Oscillation drive cycles of sea-level change of several tens of centimetres over periods of several years (Thomson et al., 2008). Over the longer term, the slow background rise in mean sea level projected for many locations in Canada will cause extreme water-level events to occur more frequently. The effect may be pronounced for locations such as Halifax and Tuktoyaktuk that have high rates of projected relative sea-level rise. Here, extreme water-level events having a present return time of several decades are projected to recur every few years or even more frequently by the end of the century (*see* Chapter 2; Forbes et al., 2009; Lamoureux et al., 2015).

In summary, projected relative sea-level change in Canada varies substantially due to differences in vertical land motion and other factors. In some locations in the East Coast region, projected relative sea-level change exceeds projected global values, but projected relative sea-level change in most localities is less than the global value (James et al., 2014 [Figure 9], 2015). Across large portions of the North Coast region, relative sea level is projected to continue to fall due to land uplift.

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FAQ 7: HOW WILL CLIMATE CHANGE AND SEA-LEVEL RISE AFFECT COASTAL ECOSYSTEMS?

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Coastal environments in Canada encompass a complex array of linked terrestrial, aquatic and marine ecosystems. Throughout much of the country, limited information on trends in health of coastal ecosystems, especially in environments distant from human populations, constrains effective planning for change. Since the arrival of European settlers, land-cover and -use patterns along Canada's southern coasts have changed from largely forested to predominantly agricultural and urbanized. These changes in diversity and ecosystem services can greatly affect the capacity of coastal ecosystems to respond and adapt to any changes.

Climate change in Canada already contributes to change in coastal ecosystems, causing loss of habitats, species migration, shifts in productivity, changes in ecosystem functions and services, and rising sensitivity to nutrients and pollutants. Warming in the environment jeopardizes survival of some wild species unless they can migrate farther north. In some areas of the coast, anticipated changes in the physical environment, driven by sea-level rise or other climate-related phenomena, may occur at a pace that exceeds the capacity of species and ecosystems to adapt. Alternatively in some areas, changes in climate may improve conditions for some species and create opportunities for new or enhanced ecosystem services. Ensuring the sustainability of ecosystems and ecosystem services requires an understanding of the cumulative effects of climate change and increasingly severe weather, along with the relationships among forests, rivers, marine waters and people.

Scientists struggle to predict which species and communities in coastal ecosystems will be most at risk, as well as where and when tipping points (points where rapid catastrophic change is initiated) will be reached. However, a growing body of Canadian and international literature addresses the negative and, in some cases, positive effects of changes in air and water temperature, shifting precipitation patterns, rising sea level and severe weather events on the fauna and flora in coastal areas. The key findings about these effects in Canada include:

- Changes in the productivity of terrestrial ecosystems (e.g., forests and wetlands) will impact the survivability of native species and may improve conditions for invading species. Extended periods of heat and drought will enhance conditions for wildfires. Changes in vegetation, coupled with increases or decreases in seasonal precipitation loads in watersheds, will change the timing of peak riverine flows, and flooding or droughts will affect aquatic ecosystems, altering species and habitats. Increased rates of erosion in streams resulting from higher peak flows, changes in the loading and deposition of sediments, and altered nutrient loads from overland runoff will affect the productivity of nearshore waters, as well as the physical and biological health and functioning of salt marshes.
- In nearshore marine waters, higher sea temperatures will affect predator-prey relationships in the food web by disproportionately favouring some species (e.g., predators or prey) and by changing the timing of food availability. Warmer waters may increase competition for food and habitat among some species, as southern species extend their range farther north and new species are introduced. Strong evidence already indicates a northward shift in snow crab, for instance, pushing them farther from populated coastal communities. Higher water temperatures also increase the frequency and magnitude of disease outbreaks for both aquaculture and wild fish and shellfish populations. Warmer water temperatures associated with lower water flows in rivers may challenge the survival and/or reproduction of cold-water fish species, such as trout and salmon.
- Acidification of sea water from rising concentrations of carbon dioxide adds significant concern. In some areas of all three coasts, waters already considered corrosive to some forms of calcium threaten the integrity of shells and skeletons. Higher acidity reduces the growth and survival of shellfish species such as clams and oysters and will likely reduce catches in important sea fisheries (e.g., oysters, mussels, sea urchins). Ocean acidification may also affect the performance of pink salmon in both fresh-water and nearshore marine waters. Ocean acidity will continue to increase during the 21st century, and it is worth noting that some of the geoengineering solutions that have been proposed to limit increases in temperature will not reduce ocean acidification.
- Rising concentrations of nutrients in coastal waters resulting from agricultural run-off and urbanization (as well as more intense precipitation events) will increasingly stimulate phytoplankton blooms that eventually sink and decompose, depleting the water of oxygen. Such eutrophication can lead to hypoxia (depleted oxygen) in coastal waters, creating dead zones where fish and invertebrates struggle to survive. Progressively worsening hypoxia in the deep waters of the Gulf of St. Lawrence, especially in some regions, drives away many fish, mollusc and crustacean species, including Atlantic cod.

- Rising sea levels in parts of the country and higher storm surges will increase rates of erosion and change patterns of sediment deposition. Warmer sea-surface temperatures will also reduce nearshore ice cover, increasing exposure to winter storm surges and larger waves, accelerating erosion on some shores and changing local topography, water depths and current patterns. Increased exposure and more severe storm events may also promote resuspension of contaminated sediments in shallow coastal waters and harbours.
- Rising sea level and more frequent storms may erode or flood vulnerable salt marshes, dune formations and eelgrass beds, pushing them inland or eliminating them partly or completely. Salt marshes, eelgrass beds, beaches and other ecosystems will be threatened where shoreline topography or engineered structures such as dikes prevent landward migration. For example, Roberts Bank, BC, an ecologically critical area, supports more than 300 species of birds and more than 80 species of fish and shellfish. Dikes built in the early 20th century to stabilize the coastline now prevent intertidal vegetated areas, including coastal marshes, from migrating in response to sea-level rise, thus eliminating critical marsh habitat (Figure 6). Changes in seasonal precipitation will also affect the health of salt marshes, altering nutrient influx and increasing the occurrence of floods and droughts.
- In Canada's North, terrestrial ecosystems will struggle with changes in seasonality, loss of snow and ice, and thawing permafrost. Shorelines will become more unstable, altered by increased erosion, changes in depositional patterns and flooding, all of which will affect local ecosystems and the well-being of human communities dependent on traditional hunting and fishing. Declines in sea ice will reduce birthing habitat, and impair hunting activities for species such as polar bears, seals and walrus. Greater access to Arctic waters will also increase the potential for human activities such as shipping and oil-and-gas production, and the likelihood for pollution, contamination and species introductions associated with these activities. Noting the fragility of these Arctic coastal ecosystems and the distances from emergency-response services, pollution may become widespread and irreversible, with severe consequences for productivity and biodiversity.

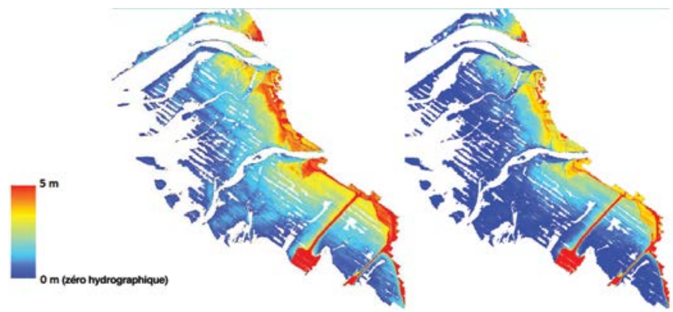

FIGURE 6: Effect of a 0.88 m sea-level rise on Roberts Bank. Cyan and blue tones denote areas below mean water level, with higher vegetated areas depicted in yellow and orange tones (Hill et al., 2013). The result is a significant decrease in the extent of the upper vegetated zones, which include highly brackish marshes. The Port Metro Vancouver and Tsawwassen Ferry terminals, the two linear structures shown in orange, extend onto the Bank.

The current state of scientific knowledge cannot predict with confidence the effects that climate change will bring to Canada's coastal environments because of limited knowledge of how quickly organisms can adapt or exactly how different environmental variables will interact with ocean life. Although some positive change may occur for species that thrive in warmer waters or different species mixes, many changes will have negative impacts relative to oceans past and present. A sea change in oceans is one certainty associated with climate change.

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FAQ 8: HOW WILL SECTORS IN COASTAL REGIONS BE IMPACTED BY CLIMATE CHANGE?

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Industries and businesses in coastal regions are facing a range of challenges and opportunities associated with climate change. In addition to rising temperatures and shifts in precipitation patterns, they are dealing with sea-level change, coastal erosion, flooding and, in northern regions, significant reductions in sea-ice cover and permafrost degradation. These impacts can have major economic consequences: studies estimate that, by 2020, annual economic damages from sea-level rise and storm surges in Canada could be $2.6–5.4 billion, and could reach $48.1 billion by 2080 (Stanton et al., 2010). Examples of impacts on specific sectors are highlighted in this FAQ, focusing on four (fisheries, tourism, energy and transportation) that depend on the coastal environment for their operations. Further details can be found in the regional chapters (*see* Chapters 4–6), as well as in Chapter 3 ('The Coastal Challenge') of this report.

FISHERIES

Canada's marine fisheries are an important component of the economy and culture in coastal regions. The impacts of climate change will be felt primarily through effects on individual species (e.g., health, populations and distribution) and on fishing infrastructure (e.g., ports, wharves, piers), with the degree of impacts, and their importance, differing by region, subregion and type of fishery (e.g., commercial, aquaculture, traditional and recreational).

Most fish species are sensitive to changes in their environment. For example, a study of fish stocks off the coast of eastern North America found that 26 (out of 36) fish species shifted northward in response to increased water temperatures between 1968 and 2007 (Nye et al., 2009). Such shifts have both negative and positive implications for the timing of fishing seasons and the species available for fishing. In the North, for example, there are potential opportunities for new commercial fisheries as a result of a northward shift in the distribution of cod and other species (*see* Chapter 5).

Climate change is also associated with increased ocean acidity and decreased levels of oxygen (hypoxia). Commercially valuable shellfish on the east and west coasts are vulnerable to acidification during many stages of their development. Hypoxia can result in reduced stocks of both finfishes and crustaceans through impacts on fish mortality, development and growth. The shellfish industry is also vulnerable to increases in exotic-species invasions associated with warming waters, and closures from biological contamination. For example, shellfish closures along the coast of Nova Scotia have increased steadily since the 1940s and, in 2000, 60% (277 harvesting sites) of the shellfish areas were closed (CBCL Limited, 2009).

Fisheries are also impacted by the effects of extreme weather events, sea-level rise and erosion on coastal infrastructure. Climate change–related damage to ports, wharves and piers is a key concern identified by Fisheries and Oceans Canada.

TOURISM

Tourism in coastal areas depends heavily on the natural environment and the services it offers (e.g., beach visits, fishing, boating and hiking). Although research on the relationship between climate change and tourism in Canada is limited, it suggests that there will be both positive and negative impacts.

Benefits in the East Coast and West Coast regions tend to be related to longer seasons for tourist visits and summer recreational activities (e.g., golfing and fishing). However, sea-level rise and the impact of extreme weather present risks to tourism infrastructure (e.g., wharves and coastal properties), cultural resources (e.g., Haida Gwaii and L'Anse-aux-Meadows) and beaches (e.g., Prince Edward Island National Park). Warmer waters may also make the beaches less attractive if there are associated increases in algal blooms and decreases in water quality.

In the North, greater opportunities for cruise-ship tourism due to reduced sea ice are expected (*see* 'Transportation' section), with trends indicating that this has already begun (*see* Chapter 5). In the southern Hudson Bay region, however, cruise-ship and other tourism activities may decrease as species that attract visitors, such as polar bears, shift northward (*see* Chapter 5).

ENERGY

In the North, reduced sea ice and a longer navigable season may present opportunities for the oil-and-gas industry with respect to exploration and development. Potential offshore reserves in the western Arctic have been estimated at up to 150 trillion cubic feet of natural gas and more than 15 billion barrels of oil (Government of the Northwest Territories, 2015). Oil companies have indicated interest in developing new offshore oil platforms, such as in the Beaufort Sea (*see* Chapter 5).

In British Columbia, existing and planned energy-related infrastructure along the Pacific coast has been valued in excess of $100 billion (*see* Chapter 6), and recent interest in energy development and shipping has led to growth in some communities on BC's north coast. In these communities, climate change impacts of concern relate to sea-level rise and increased storminess, which can affect coastal export terminals and create hazardous conditions for shipping.

Increased damage to energy-transmission infrastructure is an issue for all regions. In the North, for example, there are concerns regarding the impact of potential increases in freezing-rain events and stronger storms on electrical wires (*see* Chapter 5). Changes in streamflow patterns can affect hydroelectricity production, either positively or negatively (Lemmen et al., 2014).

TRANSPORTATION

Throughout Canada (including in the coastal regions), most transportation infrastructure, including roads, rails, bridges, ports and airports, has not been built to withstand future climate extremes and coastal erosion. For the transportation sector, potential impacts include disruptions to ferry and airport services, road closures and costly damage to infrastructure (Figure 7). There are also potential opportunities for the sector, mostly for shipping, associated with reduced sea ice and deeper water in harbours.

FIGURE 7: Damage to the highway and bridge near Port Rexton, NL due to Hurricane Igor. *Photo courtesy of Fire and Emergency Services, Newfoundland and Labrador.*

Reliable transportation networks are required for trade, economic competitiveness and resilient and safe communities. In the East Coast region, large volumes of goods travel by rail and road between the provinces of New Brunswick and Nova Scotia through the low-lying Chignecto Isthmus. If this route were to be blocked, it would stall $50 million in trade per day (*see* Chapter 4). Flooding of rail lines located on floodplains in British Columbia can result in a temporary loss of access to ports (*see* Chapter 6), and rural coastal communities can become cut off when highways are flooded. Five airports in British Columbia are exposed to increased risk of flooding as a result of sea-level rise and storm surges due to their low elevations (<5 m above sea level; *see* Chapter 6).

Ferry services are an important component of the transportation system in both the East and West Coast regions. Disruptions to ferry services can isolate communities and reduce access to services. 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). Such disruptions are a concern for many small communities on Vancouver Island and several areas in the East Coast region.

With reduced sea ice, increased marine traffic in the North is expected and northern ports may become more viable (*see* Chapter 5). This presents opportunities for cruise-boat tourism (with potential employment and income-generating benefits), cargo shipping (e.g., for resource activities, community supply and moving resources south) and development of natural-resource industries, such as mining. The northern sea routes also provide a shorter trip between Europe and Asia, with significant potential cost savings for the shipping industry. However, there are associated risks (e.g., from ice damage and other marine hazards) and the North Coast region has limited sea charts and search-and-rescue capacity.

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FAQ 9: WHAT IS BEING DONE TO ADAPT TO CLIMATE CHANGE IN CANADA'S COASTAL REGIONS?

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As is evident throughout the regional chapters of this report, adaptation is currently occurring in all of Canada's coastal regions. Types of adaptation include plans and strategies, institutional changes (such as updating policies, legislation and regulations) and on-the-ground implementation of measures to reduce vulnerability (e.g., beach nourishment and wetland restoration). This FAQ highlights some of the activities being carried out in each coastal region of Canada to reduce current and future vulnerability to climate change. It provides an overview and examples; further information on the specific adaptation measures can be found in the regional chapters of the report (*see* Chapters 4–6), while discussion of adaptation in general is presented in Chapter 3 ('The Coastal Challenge').

EAST COAST REGION (CHAPTER 4)

An inventory of vulnerability assessments conducted since the late 1990s in the East Coast region counted 226 individual studies, most of which focused on coastal erosion, flooding and ecosystem restoration (*see* Chapter 4). This demonstrates the considerable work being done to map and understand vulnerabilities to climate change, and to raise awareness of the risks presented by sea-level rise and storm damage.

Hard-protection measures, such as rip-rap, seawalls and groynes, are among the most common approaches to reduce risks from coastal erosion in the region. Although the use of such hard-protection measures has been increasing, they can serve to actually increase rather than reduce vulnerability, especially for adjacent lands, if they are not designed and placed properly or adequately maintained. Risks include accelerated erosion, loss of beaches and coastal squeeze of habitats and ecosystems. Soft-protection measures (such as the use of clean sand from dredging to replenish beaches) offer alternatives to hard approaches.

Accommodation approaches have been used by some municipalities to reduce risks from flooding and other hazards. For example, the Municipal Planning Strategy and Land Use By-Law for the downtown Halifax waterfront area requires any ground-floor elevation development to be a minimum 2.5 m above the ordinary high water mark. Avoidance and retreat strategies have also been used in the region to reduce vulnerability to sea-level rise. In Prince Edward Island National Park, for instance, the decision was made to abandon some campgrounds and relocate the main coastal road landward to deal with coastal erosion.

NORTH COAST REGION (CHAPTER 5)

The North has been warming much faster than the rest of Canada, with widespread and severe impacts already being observed. As a result, there has been considerable attention on climate change adaptation in the region, with many adaptation plans and initiatives in place. All levels of government are active on adaptation. For example, Indigenous and Northern Affairs Canada has a program to reduce vulnerability of community infrastructure to climate change; the Nunavut and Yukon territorial governments both have formal adaptation strategies in place; and several communities have developed adaptation plans that focus on increasing the resiliency of the built environment.

Much of the adaptation work in the region has focused on dealing with changes in permafrost and sea ice. For example, new standards that factor in climate change have been developed to inform building on permafrost. A study in three coastal settlements in the Northwest Territories concluded that 'informed adaptation' could reduce the cost of impacts from permafrost degradation by one-third relative to the cost when no action is taken (*see* Chapter 5). To adapt to changing patterns of sea ice, new technologies are being used to share information on sea-ice thickness and other surface features to reduce safety risks (associated with travel on sea ice, for example). For instance, SmartICE (Sea-Ice Monitoring And Real-Time Information for Coastal Environments) is a sea-ice information gathering and dissemination system being piloted with communities in Nunatsiavut and Nunavut.

Access to information is a barrier to adaptation that is being addressed through many initiatives, including an online portal developed under the Arctic Council. This adaptation information portal was developed to facilitate knowledge exchange on climate change adaptation in the circumpolar north and serve as an information hub for those making decisions on the issues (e.g., communities, researchers, public and private sectors). Access to the portal is through the Arctic Adaptation Exchange website (http://www.arcticadaptationexchange.com).

WEST COAST REGION (CHAPTER 6)

In the West Coast region, the risks associated with sea-level rise and coastal flooding have received considerable attention by the provincial and local governments. Several local governments have begun planning for sea-level rise. Examples of recent adaptation projects include a cost assessment of upgrading Metro Vancouver's dike system; a risk assessment of sea-level rise in the Victoria Capital Regional District; and the placement of boulders below the low-tide level off the West Vancouver shore to reduce impacts from storm surges. Important economic hubs (e.g., Vancouver International Airport and the Port of Metro Vancouver) are also working with neighbouring municipalities on adaptation.

At the provincial level, British Columbia has updated guidelines for development in flood-risk areas, and municipalities are beginning to incorporate sea-level rise into Flood Construction Levels. 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, and the city is currently evaluating a number of other development-planning options. Guidelines are available to support engineered approaches to adaptation (e.g., coastal protection structures, such as dikes), and work on promising nontraditional protection approaches, such as wave attenuation, is underway in the region.

FAQ 10: WHO IS RESPONSIBLE FOR ADAPTATION IN COASTAL REGIONS?

Author: Patricia Manuel *(Dalhousie University)*

Adaptation to climate change in coastal regions is a shared responsibility that involves actions by all levels of government, community organizations, the private sector, academia and individuals. This FAQ illustrates the roles and responsibilities of the different groups in preparing coastal areas for climate change broadly, rather than addressing specific climate impacts.

In coastal regions, governments use a range of tools and mechanisms to protect public health and safety, guide and regulate the use of land and coastal waters, and protect environmental quality. Governments also build knowledge about climate change and the impacts on coastal environments by conducting and supporting research, and providing information and advice. Governments can set good examples through their own responses to climate change: they can demonstrate best practices of where and how to build, develop or operate in coastal locations to minimize impacts on coastal systems and to protect public investment.

The federal government, through a wide range of departments, has multiple roles at the national scale, including building and transferring knowledge; providing frameworks for co-ordinated action; implementing and supporting adaptation, including actions by Indigenous communities; and regulating the use of, and access to, coastal waters and the seabed, including the intertidal zone (the area between high and low tide). The federal government also sets the national rules, regulations and requirements that protect public health and safety, and establishes codes and standards for design and construction of infrastructure. Conditions at the coast are challenging, can be extreme (e.g., storm surges, hurricanes, ice jamming and rafting) and are changing (e.g., accelerating erosion, loss of sea ice and thawing permafrost). Revising codes and standards as necessary is part of adapting to coastal environmental change.

Provincial and territorial governments also build knowledge about climate change and adaptation specific to the coastal systems, coastal uses and development patterns in their jurisdiction. Provincial governments regulate land, air and fresh-water environmental quality, and have a role in setting infrastructure design and siting codes and standards. With the federal government, they share responsibility for regulation of the intertidal coastal environment and for emergency preparedness (along with municipal governments). They also manage and regulate land and resource development, set policies and make laws about where and how to develop land, and can protect land and special environments from development (e.g., coastal wetlands and beaches). Through land-use policy and regulation, in particular, they can establish the type and intensity of land use in coastal regions across their jurisdiction and can move development back from the coast in order to protect people and investment from coastal hazards, and coastal environments from development impacts. Both strategies—protecting people and protecting environments—are key objectives of adaptation.

Local governments (the governments of cities, towns, villages, amalgamated regions and rural districts) are often best positioned to influence coastal land use and put adaptation measures in place. Provincial governments typically delegate land-use planning and regulation to local governments through enabling legislation. Local governments can take the broader provincial policies and frameworks, where they exist, and refine them for the local context; or they can create their own planning and development rules (maintaining at least the minimum provincial requirements). In this way, local governments can control the details of land use and development in coastal regions in their jurisdiction through planning and regulation, and through site-specific planning and design. Local governments, however, have varying levels of capacity (e.g., human and financial resources) to address the issue, and not all local governments choose to practice land-use planning and land-development control. Where there are no local-level planning and controls, provincial policies and regulations still apply.

Private industry and business owners and operators, and private land owners are responsible for adhering to the requirements, standards, laws and regulations that control development and activity in the coastal regions. They must also ensure the resilience of their buildings and structures through proper design and maintenance, and they should have the appropriate safeguards in place (e.g., insurance, flood protection, emergency plans) to deal with extreme weather events. It is important to understand that the rules that protect the private sector (and their investment) from coastal hazards also serve to protect the environment from their coastal-use activities. Where the rules are not yet developed, or have not been updated to reflect changing environmental conditions, paying attention to what is happening at the coast and being informed about the best approaches for development will help private operators and property owners to make sustainable decisions over the long term.

Community, nongovernmental and professional organizations, and educational institutions also have roles in adapting in coastal regions. Community and nongovernmental organizations represent the special interests of citizens. In the context of adaptation for coastal regions, these organizations help build awareness about climate change and its impacts, and advocate for adaptation through, for example, coastal environmental protection and improved land-planning and land-development practices. Professional associations establish codes of practice and provide guidance to their members on operating in the coastal region. For example, engineering, architecture and planning are professions with roles for developing and/or promoting standards for best practices of building, design and development in coastal regions. The real-estate and insurance professions complement this effort by encouraging people (through disclosure of information and through insurance availability and rates) to make good choices about where to buy coastal property and where to build when they do buy coastal land. Educational institutions—universities and colleges, in particular—have specific capacity to build knowledge about climate change and the coast, and to transfer that knowledge broadly to ensure the highest standard for adaptation in coastal regions and help educate and inform the public about coasts and climate change.

In coastal regions, the complexity of the environment, the diversity of interests and the wide range of regulations and controls mean that a co-ordinated, multistakeholder approach to adaptation is required. A common understanding of the challenges, and common goals, supported by strong information, frameworks, standards and rules, will help ensure that the different groups can work together effectively toward adapting to climate change in coastal regions.

FOR MORE INFORMATION

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FAQ 11: HOW DO THE COSTS OF CLIMATE CHANGE IMPACTS COMPARE TO THE COSTS OF ADAPTATION?

Authors: Jimena Eyzaguirre *(ESSA Technologies Ltd.)* and Gerett Rusnak *(Natural Resources Canada)*

Knowledge of the social, economic and environmental costs of climate change impacts and of adaptation measures in coastal marine areas of Canada is limited. A few studies, at different scales, have been undertaken in recent years. These studies provide a partial picture, generally capturing only a narrow range of the full costs. They rarely differentiate the added cost that future climate change presents to coastal systems already subject to risks in today's climate. Nevertheless, these studies together suggest that adaptation measures can generate benefits exceeding their costs by reducing damages from climate-related coastal impacts. However, for some locations and for some measures, adaptation costs can outweigh the benefits. The studies also indicate that the relative costs and benefits of different types of adaptation measures—such as nature-based and engineered protection, flood-proofing or relocation—can vary considerably between locations.

A national-scale analysis by the National Round Table on the Environment and the Economy (NRTEE) estimated the cost of flooding damages to homes from sea-level rise and storm surge along Canada's coastlines (NRTEE, 2011), under a variety of future climate and economic- and population-growth scenarios, at $4–17 billion per year (in 2008 dollars, undiscounted) by the middle of the century. This represents 0.2–0.3% of projected annual GDP levels, and climate change is responsible for 20–49% of these damages. The same study found that more than 90% of coastal-flooding damage nationally would occur in British Columbia, where the concentration of people and assets vulnerable to sea-level rise and storm surge is greater than in other parts of Canada. A recent national study, which incorporated a wider range of costs but employed the lower bound of future economic- and population-growth scenarios from the NRTEE study,[2] estimated the combined cost of sea-level rise and storm surge in coastal provinces and territories of Canada during the period 2009–2054 at a cumulative total of $53.7–108.7 billion (expressed in terms of present-value GDP, given in 2008 dollars, discounted at 4%), depending on the extent of future climate change (Withey et al., 2015).[3] At the local level, a few community-scale studies have been conducted to estimate the property or land values at risk from sea-level rise, storm surges and/or erosion made worse by climate change. Estimated costs vary widely between cases but can be in the millions or even billions of dollars for some communities (McCulloch et al., 2002; BGC Engineering Inc., 2009; Hallegatte et al., 2013; AECOM, 2015). Aside from differences in scope, assumptions and methods, variations relate to the extent of vulnerability to climate change (e.g., number and value of assets and services exposed to climate-related hazards).

COMPARING RESULTS BETWEEN STUDIES

Comparing results of studies estimating the costs of climate change is difficult due to variations in scope, assumptions and methods. Variations in scope include differences in the type and number of climate-related hazards examined (e.g., coastal flooding, coastal erosion, storm surges), as well as differences in the extent to which cost estimates reflect the relevant, direct physical impacts (e.g., damage to private property and public infrastructure, habitat loss) and indirect impacts (e.g., disruption of transportation and business, lost economic productivity, changes in wages and prices, mental health effects). Different assumptions about the future (rate and magnitude of changes in climate conditions, and rates of population and economic growth) and about the extent of adaptation action already underway also contribute to variations in estimates. Methods vary considerably, ranging from basic direct-costing techniques to economy-wide modelling.

Studies that compare the costs of coastal impacts related to climate change with and without adaptation suggest that planned adaptation can reduce costs substantially. Analysis presented by NRTEE (2011) found that banning new homes in areas projected to be at risk of flooding by 2100, and relocating homes from at-risk areas after flooding occurs, result in a 96–97% reduction in aggregate cumulative damages. Another study found that for land that is highly sensitive to sea-level rise, investing in shoreline protection in the amount necessary to mitigate against any impacts from current and future climate-induced sea-level rise and storm surge is economically beneficial for almost all coastal provinces (Withey et al., 2015).

At a local level, cost-benefit analyses (CBAs) of adaptation options to reduce erosion and flooding in coastal communities are starting to be undertaken. One such analysis, for the Municipality of Sept–Îles (*see* Chapter 4; Tecsult Inc., 2008; Ecoressources, 2013), determined that the preferred adaptation strategy from a cost-benefit perspective would yield net benefits to the community with a net present value estimated at more than $850 000 (2008 dollars) during the 25-year period assessed. This adaptation strategy included a combination of proactive relocation and replenishment of sand on shorelines to slow erosion (a form of 'beach nourishment'). By adopting this strategy, the municipality could avoid losses of $15.8 million (2008 dollars) in net-present-value terms that would have occurred in the base case (do nothing until relocation is required).

Studies evaluating adaptation options also shed light on strategies that may be most beneficial or least costly for small communities and localized sites. 'Holding the line' with hard-engineering structures makes the least economic sense in some local-level CBA studies, especially when social and ecological values are considered. The CBA for the Municipality of Sept–Îles, for example, showed that the most economically beneficial adaptation strategy involves beach nourishment in six of thirteen coastal sites assessed, and proactive relocation in another six of these sites. In contrast, the two options that focused on hard-engineering solutions (e.g., barriers and breakwaters along shorelines) were shown to be more costly than the base case for all sites assessed.

Early results from a CBA for the touristic waterfront of the historic village of Percé, QC show that all adaptation options assessed would avoid climate change costs and offer an overall benefit in consideration of economic, social and environmental benefits and costs.[4] The most beneficial option is beach replenishment with large pebbles, whereas hard engineering structures are less beneficial.

A British Columbia study profiling three local-level coastal sites assessed 'soft armouring' (e.g., beach nourishment and the addition of nearshore rock features) to 'hard armouring' (e.g., seawall elevation and sea-dike construction) alternatives

2 Withey et al. (2015) employed estimates of the direct-damage costs to homes, agricultural land and forest land in Canada's coastal areas from sea-level rise and storm surge found in Stanton et al. (2010) to model the indirect costs of these damages due to changes in prices and wages associated with the loss of land and capital, across the economies of six coastal provinces (the Atlantic provinces, Quebec and British Columbia) and the three territories using economy-wide models ('computable general equilibrium' models). The study excluded impacts on nonmarket values (such as ecosystem values and recreational activities); the cost of damage to public infrastructure (e.g., ports, roads and railways) and commercial property (e.g., factories, stores and marinas); and losses due to business interruption.

3 The lower end of this range corresponds to the Intergovernmental Panel on Climate Change's (IPCC) 'Rapid Stabilization' climate scenario, and the higher end of the range corresponds to the IPCC's 'Business as Usual' climate scenario (IPCC, 2000).

4 This work is part of a pair of regional economic studies led by Ouranos and the University of Prince Edward Island, through which CBA case studies are being conducted in eleven coastal locations in Quebec and the Atlantic Provinces. Further information is available at Ouranos (2014).

with respect to ecological, economic and adaptation-effectiveness criteria (Lamont et al., 2014). The study found that, for soft- and hard-armouring options offering the same level of flood protection in a scenario of climate change–related sea-level rise, soft armouring provided 30–70% greater cost savings than the hard-armouring alternatives.

The presence of high-value properties, major infrastructure, amenities and/or large populations in areas exposed to coastal impacts can strengthen the case for hard-protection options (*see* Chapter 6; McCulloch et al., 2002; Withey et al., 2015). The estimated adaptation cost of upgrading the 250 km of diked shorelines and low-lying areas of Metro Vancouver to protect current populations and high-value assets from a 1 m rise in sea level and a once in 500 years flooding event is $9.47 billion (2012 dollars; Delcan Corporation, 2012). For comparison, an estimated $33 billion of assets are currently exposed to a once in 100 years flood in Vancouver (Hallegatte et al., 2013). Research to estimate the potential costs avoided or reduced through enhanced flood protection in British Columbia's Lower Mainland is underway, but previous analysis suggests the avoided costs could be substantial. For example, the City of Chilliwack's 2009 flood-risk assessment found that damage and loss from a single dike-breach event could exceed $1 billion (BGC Engineering Inc., 2009).

Although basic cost-benefit analysis can be a useful tool to help inform adaptation decision making, it is important to recognize that the best adaptation option may not be the one that appears so from a simple comparison of costs and benefits. There may be added value in adaptation options that are more flexible and reversible, given uncertainties related to the magnitude and timing of damages and the effectiveness of adaptation options. Economic analysis that incorporates the value of flexibility can help inform strategies to manage coastal risks adaptively in light of uncertainty (Gersonius et al., 2012).[5] Moreover, the distribution of costs and benefits of adaptation among groups in society can be uneven (e.g., all tax payers may contribute to shoreline protection but only a small group of property owners may benefit). By disaggregating results geographically and/or by social groups, economic analysis can help decision makers address questions about the fairness of adaptation options (e.g., Boyd et al., 2012).

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5 This includes economic analysis in a risk-management framework that provides guidance on balancing adaptation timeframe and cost considerations, and approaches such as 'real options' that can test alternative investment paths over time (Gersonius et al., 2012; Lin et al., 2014).

FAQ 12: WHERE CAN I FIND ADDITIONAL RESOURCES ON ADAPTING TO CLIMATE CHANGE IN COASTAL REGIONS?

Author: Mary-Ann Wilson *(Natural Resources Canada)*

There are many resources and tools available to aid in the planning process for adaptation to climate change. These can help with all stages of the adaptation process, including getting up to speed on the issue, learning how climate will change in your region, assessing climate sensitivities, building capacity to adapt, implementing adaptation and sharing your successes (and lessons learned) with others. This FAQ highlights some key resources to help Canadian stakeholders get started on adaptation.

INVENTORIES OF INFORMATION

NATIONAL

Adaptation Library (http://www.icleicanada.org/resources/item/164-adaptationlibrary):
This inventory of resources was developed by ICLEI Canada and provides a database of reports and tools to help you assess vulnerability to climate change and move forward on implementing adaptation options. Many of the resources are community focused.

Natural Resources Canada: Impacts and Adaptation (www.nrcan.gc.ca/environment/impacts-adaptation/10761):
This website provides links to adaptation resources that have been developed by, or with support from, the Climate Change Impacts and Adaptation Division (CCIAD) at Natural Resources Canada. Some of these resources include assessment reports, case studies, project reports, tools and guides.

REGIONAL

Atlantic Climate Adaptation Solutions Association (ACASA; www.atlanticadaptation.ca):
This site provides access to tools and resources that can help decision makers address coastal erosion, coastal and inland flooding, infrastructure design and groundwater management.

Coastal and Ocean Information Network Atlantic (COINAtlantic; http://coinatlantic.ca/):
This website is a hub for coastal and ocean information in Atlantic Canada. Through the site, you can access data, information and applications (including geospatial tools) relevant to Atlantic Canada.

Ouranos (http://adaptation.ouranos.ca/en/):
This site provides a searchable database you can use to access resources and information on climate change adaptation in Quebec.

Fraser Basin Council (http://www.retooling.ca/):
On this website, you can find links to project profiles, reports, guides, case studies, presentations and tools relevant to work on climate change adaptation in British Columbia.

Adaptation to Climate Change in British Columbia (http://www2.gov.bc.ca/gov/content/environment/climate-change/policy-legislation-programs/adaptation):
This provincial website provides links to summary reports on climate change impacts, indicators and the province's adaptation strategy.

Pan-Territorial Adaptation Partnership (http://www.northernadaptation.ca/):
This partnership is a collaboration between the Governments of Nunavut, the Northwest Territories and Yukon. Their website provides links to resources for addressing climate change in the North and updates on relevant activities.

Nunavut Climate Change Centre (http://climatechangenunavut.ca/):
This website is designed to help Nunavummiut learn about Arctic climate change, and how they can engage and adapt. It includes an overview of climate change in the Canadian Arctic and access to the latest research and information on traditional and local knowledge of climate change.

UNDERSTANDING AND USING CLIMATE SCENARIOS

A Guidebook on Climate Scenarios (http://www.ouranos.ca/media/publication/352_GuideCharron_ENG.pdf):
This guidebook is a tool for decision makers to familiarize themselves with future climate information. It is aimed at everyone involved in climate change adaptation, from those in the early stages of climate change awareness to those implementing adaptation measures.

Canadian Climate Data and Scenarios (http://ccds-dscc.ec.gc.ca/?page=main):
This Environment Canada website provides maps, plots and tables of projected temperature and precipitation changes for Canada. Information is available for different time ranges, and summary statistics are available for the provinces and territories.

Pacific Climate Impacts Consortium (PCIC; https://pacificclimate.org/):
Located at the University of Victoria, this regional climate service centre provides practical information on the physical impacts of climate variability and change in the Pacific and Yukon regions of Canada.

ADAPTING TO SEA-LEVEL RISE

Sea Level Rise Adaptation Primer (http://www2.gov.bc.ca/assets/gov/environment/climate-change/policy-legislation-and-responses/adaptation/sea-level-rise/slr-primer.pdf):
This resource for local governments and land-management authorities provides information on a range of tools that can be used as part of a sea-level–rise adaptation strategy.

ONLINE COMMUNITIES

Climate Change Adaptation Community of Practice (CCACoP; https://ccadaptation.ca/en/landing):
This interactive online community serves as a place where researchers, experts, policy makers and practitioners from across Canada can come together to ask questions, generate ideas, share knowledge and communicate with others working in the field of climate change adaptation.