CHAPTER 4: PERSPECTIVES ON CANADA'S EAST COAST REGION

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KEY FINDINGS

Canada's East Coast region is geographically, ecologically and socially diverse, resulting in a wide range of climate change effects and responses. Analysis of existing literature and ongoing adaptation initiatives leads to the following key findings:

- **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 21st 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 21st 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.

1 INTRODUCTION

For this report, Canada's East Coast region includes the marine coasts of the Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador) as far north as Hamilton Inlet, Labrador, as well as the marine coasts of Quebec along the estuary and Gulf of St. Lawrence up to the city of Québec (Figure 1). The region has been inhabited by aboriginal populations for at least 9000 years (Chapdelaine, 1996), with European colonization beginning in the early 17th century. Today, more than 70 ethno-linguistic communities are represented on the coast, including the First Nations peoples. The current coastal population of the region, about 3 million people, resides in a few large cities and many small towns and tiny hamlets. Population density is lowest along Quebec's North Shore and the coast of Labrador.

The East Coast region features a great variety of landscapes consisting of rich and diversified ecosystems. Coastal communities benefit from the services provided by these ecosystems (e.g., food supply and protection against wave erosion), which contribute to both regional and national economic prosperity. Resource sectors, such as fisheries, aquaculture, transportation, tourism, mining and industrial development, rely either on marine resources or on the transportation services facilitated by the marine environment.

Climate change will affect many coastal processes, as well as adjacent terrestrial and oceanic environments, in the East Coast region. Changes in sea level, storm surges and heavy precipitation events can result in failure of coastal infrastructure, shoreline erosion, coastal and inland flooding, ice pile-ups, and saltwater intrusion into surface water and groundwater. Climate change impacts also include increasing water temperature, changes in duration of ice cover, acidification and oxygen depletion that, in turn, impact marine resources and ecosystems. If severe storms (e.g., tropical or extra-tropical storms, hurricanes) increase as a result of climate warming, the potential for wind, wave and water damage will also increase. These impacts would be further exacerbated by rising sea level. Although it is widely recognized that many natural hazards related to climatic events will increase on a global scale as a result of climate warming, there is less confidence about projected changes at the regional scale (*see* Chapter 2; IPCC, 2012).

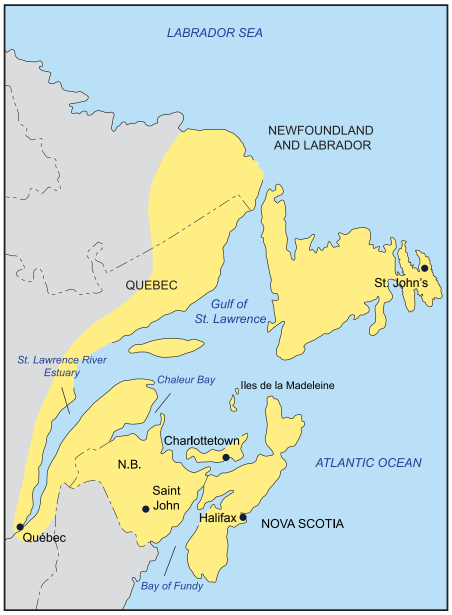

FIGURE 1: Geographic extent of the East Coast region.

Climate change will result in long-term and permanent changes in coastal regions. The impacts of climate change on marine, terrestrial and coastal ecosystems affect human communities located close to the shore, as well as those that depend on coastal ecosystems. The vulnerability of a coastal community to climate risks depends on the physical characteristics of the coast and on the management of human activities within this changing environment. These changes will impact the lifestyles, economies and sustainability of coastal communities, presenting both risks and opportunities for economic activities. Coastal communities can reduce risks and take advantage of opportunities by adapting to these evolving conditions.

This chapter begins with an overview of observed and projected changes in climate and physical and biological coastal processes in the East Coast region (Sections 2–4). This provides a foundation for understanding climate change impacts on, and vulnerability of, coastal communities and key economic sectors, which are discussed in Section 5. It concludes with a discussion of the process of adaptation and our capacity to undertake actions that reduce climate impacts and benefit from possible opportunities (Section 6). Adaptation is framed in the context of multiple drivers of change, recognizing that communities, ecosystems and industry are continually evolving in response to a wide range of pressures, most of which are unrelated to climate. Adapting to climate change is a challenge that requires leadership, imagination and inclusion of a wide variety of participants, including communities, governments, industry, academia, coastal scientists, engineers, planners and civil society.

2 OBSERVED AND PROJECTED CLIMATE CHANGES

Canada's East Coast region is already affected by the changing climate (Vasseur and Catto, 2008). The strongest climate trend relates to increased air temperatures during the last century, a trend that climate models project to continue or accelerate for the coming century (Bush et al., 2014). Other climate variables, such as precipitation, evaporation, fog, winds and snow, may also be changing, but the trends are less strong than those for temperature.

This section reviews trends and projected changes in selected key climate parameters for the East Coast region: air temperature, precipitation and ocean-water temperature, because of their global application as indicators of long-term climate change; and wind and storms, due to their strong influence on climate impacts along coasts. Further information on observed and projected climate change in Canadian coastal areas is provided in Chapter 2 (at a national scale) and in the Atlantic Large Aquatic Basin assessment (DFO, 2012b). Changes in sea level, sea ice and wave climate are discussed in Section 3 in the context of their impacts on physical coastal processes.

2.1 AIR TEMPERATURE AND PRECIPITATION

A statistically significant increase in mean annual air temperature for the period 1900–2010 is evident throughout the East Coast region (Figure 2). The data demonstrate a general warming trend with high interannual and interdecadal variability (*see* Chapter 2 for discussion of climate variability). The average warming for the East Coast region as a whole during the 110-year period of record was 0.90 ±0.37°C (Figure 2a). Stations located along the Atlantic Ocean warmed 0.75 ±0.34°C (Figure 2b), whereas those located along the Gulf of St. Lawrence coast warmed 1.12 ±0.43°C (Figure 2c). Other studies (Finnis, 2013; Galbraith and Larouche, 2013) similarly denote an increasing spatial temperature-change gradient from the southeast to the northwest across the East Coast region. Temperature increases in the region are similar to, or greater than, global average warming during this same period (e.g., IPCC, 2013).

Climate-model projections indicate that historical trends of change in near-surface air temperature are expected to continue and become more pronounced (Table 1). Average precipitation, which does not show a clear historical trend, is expected to increase in winter and spring, and remain stable or decrease slightly in summer and fall. Seasonal changes in both mean near-surface air temperature and precipitation for the East Coast region are projected to be greatest in winter (Ouranos, 2010).

2.2 OCEAN-WATER TEMPERATURE

The main ocean-water bodies in the East Coast region are made up of three distinct layers: the surface layer, a cold intermediate layer and a deeper layer (Galbraith and Larouche, 2013). Local variations are observed in many areas, especially in fiord embayments, such as Smith Sound, NL and Fjord du Saguenay, QC. Rising air temperature (Section 2.1) has changed the temperature of surface marine and coastal waters (Han et al., 2013). During the period 1945–2010, the surface-water temperature of the northwest Atlantic Ocean increased 0.32°C, with the largest increase occurring in the Labrador Sea (Han et al., 2013). Increases in surface-water temperature in the Gulf of St. Lawrence are similar to those in air temperature over the same region (Galbraith et al., 2012). On the Atlantic coast, increases of +1.04°C and +0.89°C in surface-water temperature were observed for the Labrador Sea and the Scotian Shelf, respectively, during the period 1982–2006 (Sherman et al., 2009), with a similar warming trend (+0.38°C/decade) observed for the Labrador Sea during the period 1981–2010 (Han et al., 2013).

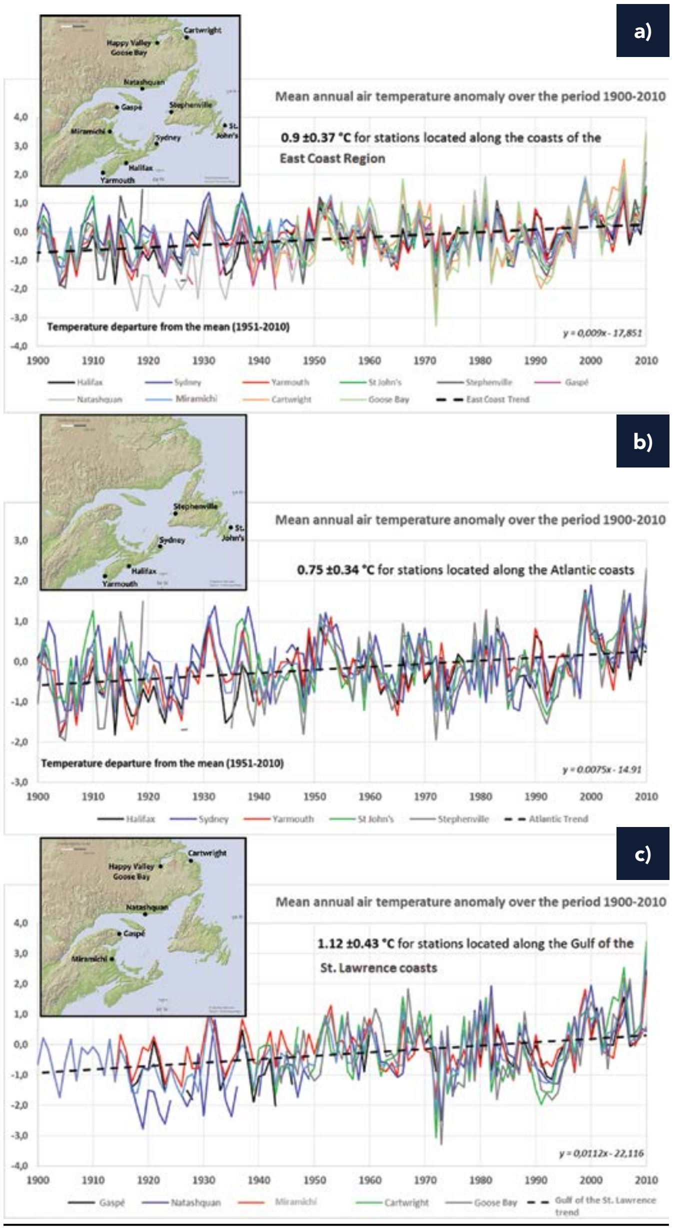

FIGURE 2: Mean annual air temperature anomaly (departure from the 1951–2010 mean) at **a)** meteorological stations in the East Coast region as a whole, **b)** stations located along the Atlantic Ocean, and **c)** stations located along the Gulf of St. Lawrence coast. The confidence interval is 95% for all plots. Positive values indicate that mean annual temperature is higher than the average temperature for the 1951–2010 time period. The 1951–2010 period was chosen as a reference period because of the availability of homogenized data (Vincent et al., 2012). Source: Ouranos (*modified from* Savard et al., 2008).

TABLE 1: Anticipated change of near-surface air temperature and precipitation in the East Coast region for 30-year periods, centred on 2020, 2050 and 2080, relative to the 1970–2000 period, based on results of the Coupled Model Intercomparison Project (CMIP 3) using *Special Report on Emissions Scenarios* (SRES) scenarios (IPCC, 2007). See Ouranos (2010) for details on methodology.

Season	Climate Parameters	Change by 2020	Change by 2050	Change by 2080
Winter	Temperature Precipitation	1.4 to 2.2°C 2.8 to 9.7%	2.5 to 3.8°C 6.5 to 15.4%	3.4 to 5.0°C 12.6 to 22.9%
Spring	Temperature Precipitation	0.8 to 1.5°C 0.3 to 8.1%	1.6 to 2.7°C 3.1 to 11.5%	2.2 to 4.1°C 8.8 to 18.5%
Summer	Temperature Precipitation	0.9 to 1.6°C –1.9 to 5.2%	1.7 to 2.7°C –1.4 to 5.7%	2.2 to 3.8°C –4.0 to 7.1%
Autumn	Temperature Precipitation	1.1 to 1.6°C –2.8 to 3.6%	1.9 to 2.8°C –2.0 to 7.1%	2.3 to 4.1°C –0.9 to 10.1%

Global-climate projections generally indicate widespread warming (1 to 3°C by 2100 under an intermediate-emissions scenario) of the upper ocean around Canada during the 21st century, with substantial seasonal and spatial variability (Meehl et al., 2007; Capotondi et al., 2012). Warming is expected to be more limited in the North Atlantic south of Greenland, due to a likely reduction in the northward ocean transport of heat by the Atlantic Meridional Overturning Circulation (Drijfhout et al., 2012; Hutchings et al., 2012). It is unclear whether this projected ocean-temperature anomaly will extend westward into the Labrador and Newfoundland coastal waters, as global models have difficulty resolving ice-ocean variability in the Labrador Sea (de Jong et al., 2009).

2.3 WIND AND STORMS

Trends in wind velocity and direction, and in storms during the 20th century, are difficult to determine conclusively, in part because datasets are not as complete as for air temperature. Wind is very sensitive to local topography, and any relocation of wind stations (even if moved a short distance) or replacement of instrumentation or equipment can introduce significant changes in a time series that are not related to climate change. The most reliable databases start only in 1961 or 1979 (when satellite observation data became available). Analysis of the density of intense storm centres over North America for the period 1961–2000 indicates that the northwestern Atlantic Ocean, the Labrador Sea and the Gulf of St. Lawrence are some of the stormiest areas in North America (Figure 3; Savard et al., 2014).

Climate projections indicate that significant changes in wind speed are unlikely as a result of climate warming, but there is likely to be a northward shift in storm tracks that will affect storm frequency in the East Coast region (Loder et al., 2013).

3 CHANGES IN PHYSICAL PROCESSES AND COASTAL GEOMORPHOLOGY

Coasts are a naturally dynamic environment (*see* Chapter 2). They are in a state of constant flux that involves sediment movement, changes in coastal morphology and shifts in the organisms that inhabit these systems. Although coastal systems may be considered as being in dynamic equilibrium, this depends on the ability of the system to transport sediment alongshore by longshore currents, or seasonally onshore and offshore through wave action. In normal conditions (excluding storms), sediment is transported alongshore through the process of littoral drift, generally within the boundaries of a littoral cell (*see* Chapter 2). Erosion or deposition rates depend on a range of natural (e.g., riverine sediment supply and formation of ice foot [ice along the shoreline]) and anthropogenic processes (e.g., dredging and shore protection).

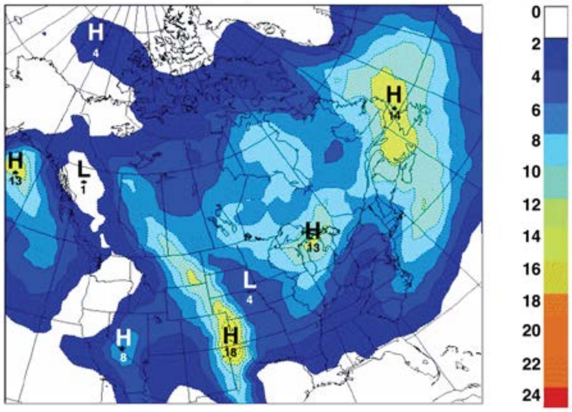

FIGURE 3: Spatial distribution of the annual average density of storm tracks for the 1961–2000 time period from ERA-40 reanalysis (a reanalysis of the global atmosphere and surface conditions for a period of 45 years, extending from September 1957 through August 2002, by the European Centre for Medium-Range Weather Forecasts; *modified from* Savard et al., 2014)

Rising air and sea-surface temperatures will lead to shorter sea-ice seasons, which in turn cause an increase in total wave energy dissipated on the coast (Neumeier et al., 2013). Combined with rising sea levels, this will affect the risk of storm-surge flooding and will exacerbate coastal erosion and sedimentation in areas already sensitive to these processes. Climate change will also affect processes, such as freeze-thaw cycles, input from inflowing rivers and ice scouring, that influence sediment balance and contribute to the changing nature of the coastal landscape.

In the following sections, the main climate change–related drivers of change in coastal geomorphology are discussed in more detail. These include the changes in sea level, storms and ice conditions that affect extreme water levels and waves.

3.1 CHANGES IN RELATIVE SEA LEVEL

Recent findings on sea-level rise (SLR) are given in global assessments, such as the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Church et al., 2013; IPCC, 2013). Global sea-level change is the vertical change of the sea surface relative to the Earth's centre, averaged for all oceans on the planet. In contrast, 'relative' sea-level change is the change in mean sea level relative to solid ground at any specific point on the coast (*see* Chapter 2).

During the 20th century and the first decade of the 21st century (i.e., 1900–2009), the trend of global sea-level rise was 1.7 ±0.2 mm/year. The rate of global sea-level rise between 1993 and 2009 increased to 3.2 ±0.4 mm/year (from satellite altimetry) or 2.8 ±0.8 mm/year (from tide-gauge records; Church and White, 2011). The IPCC (2013) projects a range of global sea-level rise of 26–98 cm by the year 2100, based on the representative concentration pathway (RCP) emissions scenarios (*see* Chapter 2). Collapse of a sector of the West Antarctic Ice Sheet has the potential to add another few tens of centimetres of global sea-level rise, but its probability of occurrence is uncertain (Church et al., 2013).

In Canada's East Coast region, spatial differences in vertical land motion, largely associated with glacial isostatic adjustment, produce regional differences in relative sea-level change (*see* Chapter 2). Glacial isostatic adjustment is the delayed response of the solid Earth to the surface unloading that occurred at the end of the last ice age. Vertical land motion measured at GPS stations in the East Coast region (*see* Chapter 2) shows sinking land across the southeastern part of the region. Sinking land contributes to relative sea-level rise. In the northwestern part of the region, the land is rising and relative sea-level change is reduced compared to global values.

Recent projections of relative sea-level change on Canadian coasts (James et al., 2014), based on the results of the IPCC Fifth Assessment Report, are described in Chapter 2. The projections include the steric effect (thermal expansion of the surface layer of the ocean); meltwater from mountain glaciers and ice caps, and the Greenland and Antarctic ice sheets; projected changes in dynamic oceanography; and other smaller sources (*see* Chapter 2). For much of the East Coast region, a projected reduction in the strength of the Gulf Stream contributes 10–20 cm to sea-level rise by 2100, due to dynamic oceanographic effects (Yin, 2012).

Projections for the East Coast region are presented in Figures 4 and 5. For the high-emissions scenario, James et al. (2014) projected the mean elevation of sea level to be 80–100 cm higher at 2100, relative to 1986–2005, in the southeastern part of the region (Atlantic coast of Nova Scotia and New Brunswick) and on the southern side of the Gulf of St. Lawrence (Figure 4). In the northwestern part of the East Coast region (i.e., on the North Shore of the Gulf of St. Lawrence in Quebec), sea level is projected to be about 20–40 cm above its current position by the year 2100. In Newfoundland, projections indicate sea-level will rise 60–80 cm by 2100. This variability is due largely to differences in vertical land motion, which range from nearly 2 mm/year of subsidence for some locations in Nova Scotia to nearly 5 mm/year of uplift on the North Shore of the Gulf of St. Lawrence. Other factors also play a role. Based on the range of estimated maximum contributions presented in the literature and summarized by Church et al.

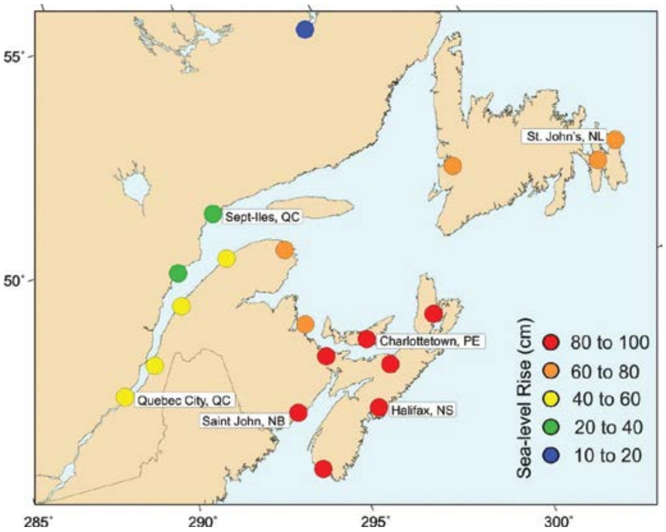

FIGURE 4: Projections of relative sea-level rise by the year 2100 for the median value of the high-emissions scenario (RCP8.5; after James et al., 2014). *See* Chapter 2 for additional information on sea-level projections. Sea-level projections through the 21st century are given in Figure 5 for the six labelled communities.

(2013), James et al. (2014) estimated additional sea-level rise associated with potential collapse of a portion of the West Antarctic Ice Sheet could contribute up to an additional 65 cm of global sea-level rise. This additional contribution has the potential to increase relative sea-level rise to more than 1.5 m by 2100 for some locations in the East Coast region (Figure 5).

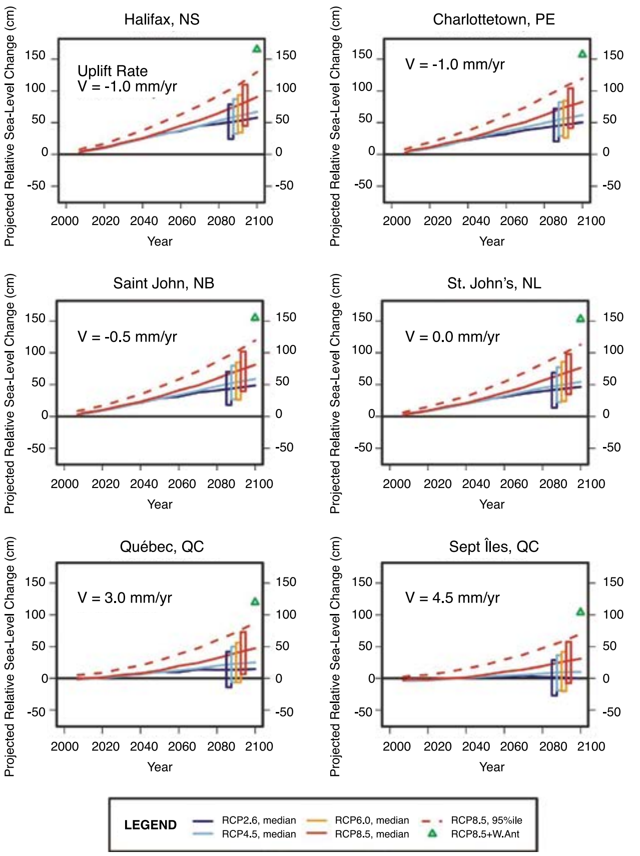

FIGURE 5: Projected sea-level change through the 21st century for selected communities in the East Coast region (after James et al., 2014, 2015). RCP2.6 is a low-emissions scenario, RCP4.5 and 6.0 are intermediate-emissions scenarios and RCP8.5 is a high-emissions scenario. The projected value at 2100 is also given for the high-emissions plus Antarctic ice-sheet reduction scenario, an augmented scenario in which the West Antarctic Ice Sheet contributes an additional 65 cm to the median projected value of the high-emissions scenario (RCP8.5+W.Ant; green triangle). Rectangles show the 90% confidence interval (5–95%) of the average projection for the period 2081–2100 and include RCP6.0. The dashed red line gives the 95th percentile value for the high-emissions scenario. Vertical land motion (V) is given to nearest 0.5 mm/year in each panel. *See* Chapter 2 for further explanation of scenarios. Projections for additional sites are given in Appendix A.

3.2 STORM SURGE AND EXTREME WATER LEVELS

Storm-surge elevation is the difference between the observed water level during the surge and the level that the tide would normally rise to in the absence of storm activity. Storm surges result from variations in atmospheric pressure and wind (*see* Chapter 2; Forbes et al., 2004; Thompson et al., 2009). Storm surges can occur over one or several tidal cycles (Figure 6), depending on the speed of the low-pressure system moving through an area. When a surge occurs at the same time as a high tide, lands and infrastructure located in low-lying areas can be flooded (Case Study 1).

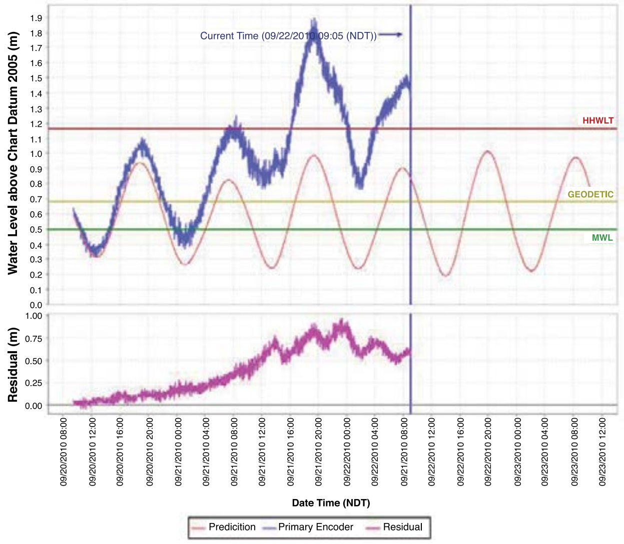

FIGURE 6: Example of surge caused by Hurricane Igor (October 2010) over several high-tide cycles in St. John's, NL. The higher high water large tide (HHWLT) was exceeded on at least three occasions (Canadian Hydrographic Service, Atlantic Region). Abbreviations: MWL, mean water level; NDT, Newfoundland Daylight Time.

CASE STUDY 1

THE GROUNDHOG DAY STORM

The 'Groundhog Day' storm of February 2, 1976 is a classic example of the impact of a storm occurring coincident with high tides to produce a large surge. Significant damage (representing more than $10 million at the time) and coastal flooding were reported in southwestern Nova Scotia and southern New Brunswick, where water levels rose more than 2.5 m above the predicted tides, heavily eroding shorelines (Parkes et al., 1997; Desplanque and Mossman, 2004). Strong south-southeast winds blowing for 5–6 hours resulted in a large storm surge in areas of the Bay of Fundy. Water levels rose to 3.2 m above predicted tides in 15 minutes (Desplanque and Mossman, 2004), and new tide-height records were set at Yarmouth, NS and Saint John, NB harbours (Amirault and Gates, 1976). Fortunately for those farther up the Bay of Fundy, the tide was an apogean spring tide (lower than average tide because the moon was most distant from Earth in its monthly orbit). Therefore, although a surge of 1.46 m was recorded and dikes were overtopped, the damage was limited. Had the storm occurred 16 days later during the perigean spring tide (higher than average tide because the moon is closest to Earth in its monthly orbit), the damage would have been much greater (Desplanque and Mossman, 2004). It is estimated that, if the Groundhog Day storm had occurred on April 16, 1976, it "would have had the potential of causing calamity on the scale of the Saxby Tide" (Desplanque and Mossman, 2004; *see* Chapter 2).

In Charlottetown, PE, the two largest recorded storm surges between 1911 and 2000 (1.43 m on December 19, 1963 and 1.41 m on March 12, 1991) did not flood the historical waterfront properties of the city, as both storm surges occurred during low tide. However, during the same time period, six smaller storm surges were sufficiently high, when combined with the tide height, to flood the waterfront area of the city, registering a maximum water level of 3.6 m or more above chart datum (Parkes and Ketch, 2002). Historically, relative sea level has been rising in Charlottetown at the rate of 3.2 mm/year since 1911 (Parkes et al., 2002). If sea levels had been at today's height, both the 1963 and 1991 storm surges would have resulted in flooding of the historical waterfront.

Using long-term tide-gauge data, Xu et al. (2012) studied the recurrence frequencies of extreme storm surges for five sites in the estuary and Gulf of St. Lawrence, and on the Atlantic coast: Lauzon, QC; Rimouski, QC; Charlottetown, PE; Halifax, NS; and St. John's, NL. Although the study concluded that there was no observed trend in storm-surge heights (i.e., no net increase or decrease) for the entire East Coast region, there were site-specific increases in storm-surge recurrences at St. John's and Rimouski during the 1922–1951 to 1981–2011 periods (Xu et al., 2012). The relative degree of negative impact on a coastal community from storm surge is also associated with the frequency of occurrence of a storm of that magnitude. Communities and coastal ecosystems that are frequently impacted by surge events are more likely to have evolved coping responses. For example, a 1 m storm surge is a relatively rare event in the Placentia, NL and Ferryland, NL areas, and could therefore pose a threat to coastal communities, whereas a 1 m storm surge in Lauzon, QC is a yearly event that may have little effect on the well-being of coastal residents.

On Quebec coasts, Bernatchez et al. (2012a) identified 30 storm-surge events that caused significant damage at a regional scale between 1950 and 2010, including 14 events that caused flooding. In the Bas-Saint-Laurent area, run-up during the storm of December 6, 2010 caused water levels to reach a little more than 2 m above the high tide (Quintin et al., 2013), corresponding to a once-in-150-years event (Bernatchez et al., 2012a). The average amount of erosion of low-lying sandy coasts as a result of this storm was 3.7 m, with a maximum erosion of 15 m measured at one site (Quintin et al., 2013).

Climate change affects storm surge and associated flooding as a result of sea-level rise, possible changes in storm frequency and intensity, and other ocean-dynamics factors. For example, tidal resonance in the Bay of Fundy is projected to increase the tidal range and lead to greater water-level extremes, although it will not affect mean sea levels (Greenberg et al., 2012). This contribution to water-level extremes has been estimated to be on the range of 5–20 cm by 2100 in the Bay of Fundy, compared with close to zero in Halifax, NS. The magnitude of changes in sea level is fairly well understood, but less is known about potential changes in other factors. Modelling allows analysis of potential storm-surge impacts under future climate conditions (e.g., Bernier et al., 2006).

3.3 WAVE CLIMATE AND SEA ICE

Wave-climate modelling (e.g., Swail et al., 2006) is used in coastal vulnerability assessments and in the planning and design of offshore and coastal infrastructure (e.g., drilling platforms, wharves, jetties, breakwaters, and offloading and loading structures). It has also contributed to an improved understanding of coastal evolution (i.e., sediment dynamics and water currents), changes in wave characteristics over time (i.e., period, height and wavelength) and possible future wave conditions in a changing climate.

Modelling of the wave climate of the estuary and Gulf of St. Lawrence for the period 2071 to 2100 indicates an increase in wave height of between 5 cm and 1 m, for a return period of 50 years, and a slight increase in overall mean wave energy due to decreasing sea-ice cover (Neumeier et al., 2013).

The East Coast region includes the most southward extent of winter sea ice in Canada's coastal waters. The average annual sea-ice cover in the East Coast region has decreased by 0.27% per year since the Canadian Ice Service began collecting data in 1968–1969 (*see* Figure 7 for trend since 1980–1981; Senneville et al., 2014). For the period 1998–2013, the average decrease was 1.53% per year (Senneville et al., 2014; note that both 2014 and 2015 had ice cover exceeding the 1980–2010 median). Warmer average winter temperatures have reduced the percentage of ice cover, shortened the duration of the ice season and decreased ice thickness. These trends are projected to continue, with modelling indicating that sea ice will be almost completely absent in most of the Gulf of St. Lawrence by 2100 (Senneville et al., 2014).

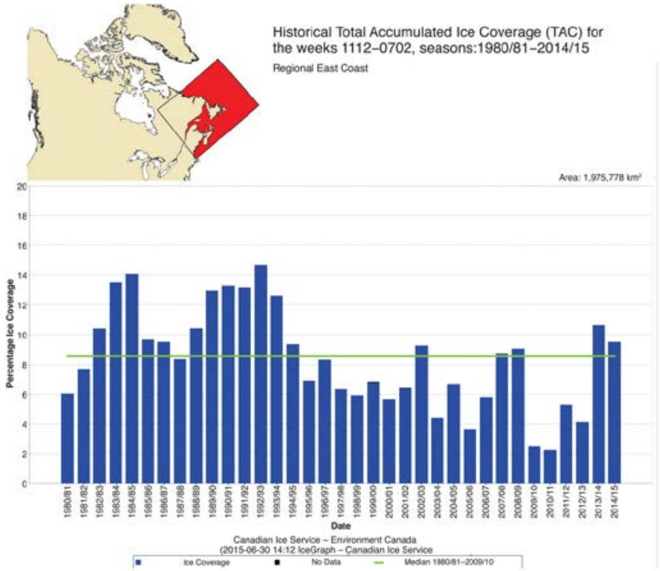

FIGURE 7: Historical total accumulated ice coverage for the weeks December 11 to February 7 from 1980 to 2015 in the East Coast region (Environment Canada, 2015).

Since ice cover impedes wave formation, the shortening of the ice season increases the total energy of storm waves developing in an ice-free water body, such as the Gulf of St. Lawrence (Neumeier et al., 2013). This, in turn, will modify the coastal sediment balance, activating shore erosion in some areas while reducing erosion in others as material is redistributed (Jones et al., 2009; Overeem et al., 2011).

In the Gulf of St. Lawrence, the period of wave inhibition by sea-ice decreased by 30% for the period 1995–2007 (average ice-covered period of 55 days/year) relative to the period 1960–1995 (average ice-covered period of 80 days/year; Savard et al., 2008). In comparing future conditions (2041–2070) to the recent past (1982–2011), modelled simulations suggest that the period of sea-ice cover will decrease by 36 days and the number of days that the ice foot completely protects the coast will decrease by an average of 33.4 days (Senneville et al., 2014). Ice-foot development currently occurs during some winters along coastlines in the southern Gulf of St. Lawrence and around the Avalon Peninsula, NL, and more frequently along the Quebec North Shore, in northeastern Newfoundland and in Labrador.

3.4 GEOMORPHOLOGY, SEDIMENT SUPPLY AND COASTAL DYNAMICS

The East Coast region has a diverse geomorphology. Mountain and fiord coastal areas are common in parts of Newfoundland and Labrador, while topographically low to moderately high, resistant bedrock cliffs, occasionally interrupted by unconsolidated coasts, are found along the northern and eastern shores of the Gulf of St. Lawrence, the Bay of Fundy coast of New Brunswick, and the exposed Atlantic shores of Nova Scotia and Newfoundland. Soft erodible cliffs are widespread along the southern and western shores of the Gulf of St. Lawrence (Prince Edward Island, New Brunswick and the Îles de la Madeleine). Resistant cliffs in the region retreat slowly, at annual rates of less than a centimetre per year (e.g., Davidson-Arnott and Ollerhead, 2011). Coastal cliffs in unconsolidated materials and in soft, nonresistant rocks are more dynamic (Bezerra et al., 2011) and therefore more sensitive to climate change. Unconsolidated, low-lying coasts consisting of salt marshes, sandy barrier islands and beaches occur mainly along the St. Lawrence estuary and western shores of the Gulf of St. Lawrence (Quebec, Prince Edward Island and New Brunswick) and on the Îles de la Madeleine, as well as along the Bay of Fundy, especially at its head. Extensive, fine-grained tidal flats and salt marshes are exposed at low tide in the upper Bay of Fundy, where tides may exceed 14 m.

During the last glaciation, large quantities of sediment were deposited offshore because sea level was substantially lower than at present (Shaw et al., 2002). Subsequent glacial isostatic adjustments (*see* Chapter 2) resulted in increasing sea levels that reworked these sediments to form many of the beaches, spits and barrier islands seen today along the shorelines of the East Coast region (Davidson-Arnott and Ollerhead, 2011). However, apart from most of Newfoundland and Labrador, the abundant sediment resources contained on the continental shelf have largely been exhausted throughout the region, so most of the sediment presently supplied to the coastal beaches is sourced from shoreline erosion, the reworking of coastal sediments by littoral currents, and materials transported to the coast by rivers and streams. This leads to a chronic sediment deficit, which can be further exacerbated by the armouring of coastlines that is frequently associated with coastal urbanization (O'Carroll et al., 2006; Bernatchez et al., 2008b; Bernatchez and Fraser, 2012).

There is presently a generalized landward retreat of the coasts (Table 2) that will continue in the future. It is important to note that, apart from Prince Edward Island and sections of the New Brunswick coast, erosion rates have not been calculated in a consistent manner or with the same standards of measurement for comparison. Progradation (seaward advance of the coast) is occurring in some localized areas, often as a result of erosion along other shoreline areas (Forbes et al., 2004; O'Carroll et al., 2006; Jolicoeur et al., 2010; Davidson-Arnott and Ollerhead, 2011). The rate of shoreline erosion is associated with the lithology of the underlying bedrock (Davidson-Arnott and Ollerhead, 2011), coastal landforms or ocean-climate factors (e.g., storm surge, tidal stage and sea-level rise).

Rates of coastal erosion will also vary depending on the type of coastal landform. For example, rates of erosion in New Brunswick are highest in beach-dune systems (averaging 0.78 m/year) and lowest for cliffs (0.26 m/year; Table 3). Coastal landforms, such as beaches, dunes or marshes, have the capacity to re-establish following major erosion events (O'Carroll et al., 2006; Ollerhead et al., 2006), whereas a cliff or bluff will only recede. Eroded material plays an important role in supplying sediment to the rest of the coastal system within a littoral cell (*see* Chapter 2).

Human actions, such as coastal armouring (e.g., Finck, 2012), sediment extraction (e.g., Hunter, 1975; Taylor and Frobel, 2009) and building of dams (e.g., van Proosdij et al., 2009), interact with natural factors to influence sediment supply and coastal dynamics. For example, a study of barrier and non-barrier beaches along the head of South Bay Ingonish and Black Brook Cove, NS showed that seasonal sand accumulation resulted in fluctuations in beach width of 10–20 m at both sites. However, backshore areas varied significantly in their ability to repair themselves (Tibbetts and van Proosdij, 2013). At Ingonish beach, it took roughly 6–10 years to rebuild the crest elevation, whereas sites where the backshore areas were excavated and lowered by human activity still had not recovered 26 years later (Taylor and Frobel, 2009). A major challenge in projecting future changes in coastal geomorphology is the complex relationship between climate, coastal dynamics and human activity (Case Study 2 and *see* Chapter 2).

TABLE 2: Examples of historical bluff or cliff rates of retreat throughout the East Coast region. These rates may not be directly comparable due to differences in methodologies and types of measurements.

Location	Retreat rate	Time period	Reference
Quebec — Unconsolidated bluffs, Gulf of St. Lawrence coast	Up to 3.45 m/year	Various	(Bernatchez and Dubois, 2004)
New Brunswick — Till bluffs, Northumberland Strait	0.26 m/year (average)	1944–2001	(O'Carroll et al., 2006)
Prince Edward Island — Sandstone and till, entire island	0.28 m/year (average)	1968–2010	(Webster, 2012)
Prince Edward Island — Till bluffs, Gulf of St. Lawrence coast	Up to 2.24 m/year	1935–1990	(Forbes and Manson, 2002)
Prince Edward Island — Till bluffs, Northumberland Strait coast	0.74 m/year (average)	1935–2000	(O'Carroll, 2010a)
Newfoundland and Labrador — Unconsolidated bluffs, northeastern Avalon Peninsula	0.1 to 0.3 m/year	Undetermined	(Catto, 2011)
Nova Scotia — Till drumlin, Cape Breton	1.38 m/year (average)	2000–2007	(Force, 2012)
Nova Scotia — Till bluff, Bras d'Or Lakes	0.33 m/year (average)	1939–2014	(O'Carroll, 2015)
Nova Scotia — Basalt-sandstone bedrock, Bay of Fundy	0.06 to 0.8 m/year	Undetermined	(Desplanque and Mossman, 2004)
Nova Scotia — Till drumlin, Gulf of St. Lawrence coast	0.27 to 0.85 m/year	1939–2007	(Utting and Gallacher, 2009)
Nova Scotia — Till bluff, Northumberland Strait coast	0.4 m/year (average)	1964–2005	(Finck, 2007)

TABLE 3: Varying rates of erosion depend on coastal landform and geography in New Brunswick. Coastal erosion has been systematically monitored in the province for 45 years (New Brunswick Department of Energy and Mines, 2015). Abbreviation: N/A, not available.

Landform	Chaleur (m/year)	Northeast (m/year)	Northumberland (m/year)	All New Brunswick (m/year)
Cliff	0.18	1.17	0.26	0.26
Dune	0.35	1.20	0.85	0.80
Beach	0.32	1.01	1.00	0.76
Salt marsh	0.17	N/A	0.30	0.28

CASE STUDY 2

INTERACTIONS BETWEEN PHYSICAL, BIOLOGICAL AND HUMAN ASPECTS OF COASTAL DYNAMICS, MIDDLE COVE, NL

To better assess the vulnerability of a coastal site, location or community, a baseline study describing the links between the physical, biological and human aspects should be carried out. Middle Cove beach, located approximately 15 km north of St. John's, NL, is a prime spawning ground for capelin (capelin rolls) and is also a sought-after tourist site during the summer. The head of the cove and the beach were characterized as extremely sensitive to erosion by Catto and Catto (2014) due to the physiography of the coast; the fact that the cove faces the north to northeast storm-wave direction; the frequency of storm events (especially since 2001); the documented effects of storm activity since 1989; and the general absence of sea ice and limited snow cover.

The physical characteristics of Middle Cove beach (a moderate-wave-energy beach composed of relatively well-rounded, medium to coarse pebbles) make it an ideal spawning site for capelin (*Mallotus villosus*; Catto and Catto, 2014). Middle Cove is also one of the most heavily used beaches on the Avalon Peninsula. On warm summer days and evenings, and during capelin rolls season, more than 150 people can be found at Middle Cove beach. This visitor pressure results in gradual flattening of the upper parts of the beach, which alters the profile, destroys or restricts cusp development and results in compaction of the sediment.

The profile of Middle Cove beach, as is the case for most beaches, evolves on a seasonal basis, adjusting to coastal conditions. Of particular importance are the winter months, at which time a convex beach profile develops when waves are unable to reach the upper beach because of snow or an ice-foot cover. During winters where an ice foot is absent, the profile becomes concave (Catto and Catto, 2014). A steeper beach profile, caused by successive storm events or the absence of winter ice-foot protection, results in coarser beach material that is less favourable for capelin spawning. Warmer air and water temperatures in future will further impede winter ice-foot development (which has not been significant since the early 2000s), while relative sea-level rise could render the upper part of the beach more susceptible to scour and thinning. This will result in a beach even less favourable to capelin spawning during the roll season, and could also have economic and cultural effects.

4 CHANGES IN BIOLOGICAL PROCESSES AND COASTAL ECOSYSTEMS

Healthy coastal ecosystems provide a range of ecological services that are essential to the well-being of coastal communities. Enhancing and sustaining ecosystem resilience is of both ecological and socio-economic importance. Coastal ecosystems are integrated across terrestrial and marine environments, exchanging nutrients valuable for overall ecosystem function and providing habitats for species across a range of life-cycle stages. Direct economic benefits arise from a range of traditional and commercial activities, including fishing, shellfish harvesting and tourism. In addition, ecosystems such as wetlands, coastal dunes, spits and barrier islands enhance the sustainability of the built environment by acting as buffer zones that protect against severe wave and storm activity (e.g., Duarte et al., 2013).

Together, changing climate and increased anthropogenic pressures have led, and will continue to lead, to modifications to coastal habitats, affecting species distribution and dynamics, as well as altering and/or impairing ecosystem structure and function (Day et al., 2008; Rabalais et al., 2009; Michel and Pandya, 2010; Rabalais et al., 2010).

The following sections examine the ecological implications of changes in ocean climate (sea temperature, hypoxia, acidification and salinity), and the interaction of climate and human activities affecting water resources and ecosystem dynamics.

4.1 IMPLICATIONS OF CHANGES IN SEA TEMPERATURE

Sea temperature affects a range of biological processes (e.g., metabolic processes and growth rates) as well as species distribution and abundance (e.g., Hoegh-Guldberg and Bruno, 2010; Pankhurst and Munday, 2011). Global ocean primary productivity has declined since the early 1980s, with most of this decline linked to increased sea-surface temperatures in high and northern latitudes (Gregg et al., 2003; Hoegh-Guldberg and Bruno, 2010; Nye, 2010).

Primary productivity in the East Coast region is also affected by the scope and duration of sea-ice cover. In the Gulf of St. Lawrence, winter sea-ice contributes to water-convection processes, an important driver of primary production by phytoplankton (Le Fouest et al., 2005; Dufour and Ouellet, 2007). As sea-ice forms, it releases the salt content of the water in the form of denser brine, which sinks. This displaces less dense, nutrient-rich deeper waters toward the surface, causing upwelling and feeding nutrients to primary producers. Sea-ice melt also plays a major role in triggering phytoplankton blooms (Hoegh-Guldberg and Bruno, 2010). The likely cessation of winter sea-ice formation in the Gulf of St. Lawrence this century will affect phytoplankton abundance, timing and distribution, and alter primary production functions in this semi-enclosed marine basin (Dufour and Ouellet, 2007).

Ice also plays an important role in the redistribution and colonization of salt-marsh cordgrass (*Spartina alterniflora*) seeds and rhizomes in the East Coast region (van Proosdij and Townsend, 2006), and is an important contributor to the sediment budget of the high marsh (Dionne, 1985, 1989; Troude and Sérodes, 1988; Drapeau, 1992; van Proosdij et al., 2006). Ice in tidal flats is also important in the dispersal of macro-invertebrates and in the dynamics of spatially separated populations of the same species (Drolet et al., 2012).

Small changes in average seawater temperature have been associated with changes in abundance and distribution of coastal vegetation, finfish and shellfish (Burkett and Davidson, 2012). For fish such as salmon and eels, which use coastal habitats (salt-marsh creeks, estuaries and rivers) during part of their life cycle, temperature-induced changes will have great effects on some of their life stages and growth (Todd et al., 2008). Spawning is of special concern, as small increases in water temperature can reduce survivorship by affecting egg mortality and hatching (Pankhurst and Munday, 2011). Increased maximum summer water temperature was an important factor in the disappearance of marine eelgrass (*Zostera*) along Chesapeake Bay (east coast of the United States), near the southern distribution limit of this species (Burkett and Davidson, 2012). The condition of eelgrass beds is also a concern for Canada's East Coast region, as it is considered a prime indicator of overall coastal-ecosystem health.

Invasive species are another risk to ecosystems associated with warming water temperatures, with potential impacts on individuals, species' genetics, population and community dynamics, and ecosystem processes (Rockwell et al., 2009). These impacts can be localized or felt more broadly across the region (DFO, 2012a). Invasive alien species can disrupt food webs, resulting in a decrease in productivity for species such as oysters and eelgrass that are important in maintaining the structure of coastal ecosystems and habitats (Rockwell et al., 2009). Some studies attribute a marked decline in eelgrass health in Nova Scotia to an increase in invasive species such as the European green crab (*Carcinus maenas*; Garbary et al., 2014.) However, direct evidence of the effects of climate change on both eelgrass and invasive species such as green crab are still limited. Many of the invasive alien species that have already entered marine waters of the East Coast region are tunicates (filter feeders) that attach themselves to rocks or other surfaces of the sea floor. The shellfish aquaculture industry (e.g., mussel, oyster) is especially vulnerable to invasion by alien tunicate species, which can form significant colonies on the cultivated shells (Klassen, 2013). Examples include Club tunicate (*Styela clava*), observed in the Gulf of St. Lawrence and off Prince Edward Island; Diplosoma tunicate (*Diplosoma listerianum*), observed in eastern Canada; and European sea squirt (*Ascidiella aspersa*), observed off the coasts of Nova Scotia.

4.2 HYPOXIA

Hypoxia (also termed the 'dead zone') can result from eutrophication of coastal waters through overloading of nutrients (i.e., nitrogen, phosphorus, silicon and organic matter), leading to a depletion of the dissolved oxygen content of the water. Hypoxia can result in fish kills and mortality losses in other species, altered physiological development and growth (including reproductive abnormalities), altered migration patterns, loss of habitat for bottom-dwelling fishes and other benthic fauna, and habitat compression for pelagic fishes. These altered conditions result in reduced fish stocks, including those of valuable finfishes and crustaceans (Rabalais et al., 2010).

Hypoxia can also be related to large-scale ocean-water circulation. Historical data reveal that hypoxia is progressively worsening in the deep waters of the Gulf of St. Lawrence, especially at the heads of the Laurentian, Anticosti and Esquiman channels (Figure 8; DFO, 2010). Oxygen levels in these areas have declined since 1932 as a result of a higher influx of warm, oxygen-poor North Atlantic water and a reduced input of oxygen-rich cold water from the Labrador Current (DFO, 2012a). Hypoxic conditions drive away many fish, mollusc and crustacean species that cannot survive in oxygen-depleted conditions. In the St. Lawrence estuary, 5% of the Atlantic cod (*Gadus morhua*) tested died within 96 hours of exposure to 28% saturation, whereas half of the fish died within 96 hours when exposed to 21% saturation (DFO, 2012a). Cod almost completely avoid those areas of the estuary and Gulf of St. Lawrence where near-bottom levels of dissolved oxygen are less than 30% saturation (DFO, 2012a).

As surface-water temperatures increase due to climate change, it is likely that water stratification will strengthen, worsening hypoxia where it currently exists and facilitating its formation elsewhere. In areas of increased precipitation, increases in fresh-water discharge may result in increased

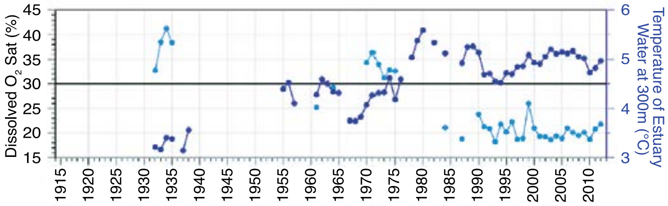

FIGURE 8: Dissolved oxygen saturation (O_2 Sat; light blue dots) and temperature (T; dark blue dots) between 295 m and the bottom in the deep central basin of the St. Lawrence estuary; 30% saturation marks the threshold of hypoxic conditions (DFO, 2010).

runoff of nutrients to coastal waters. The cumulative effect of increasing nutrient concentrations and enhanced water-column stratification will aggravate and accelerate hypoxia (Global Environment Facility Scientific and Technical Advisory Panel, 2011).

4.3 ACIDIFICATION

Increasing ocean acidification on a global scale is a major finding of the IPCC Fifth Assessment Report (IPCC, 2013). Effects of acidification include (Pörtner et al., 2014):

- dissolution of corals and carbonate exoskeletons;
- changes in benthic-invertebrate and fish productivity;
- increased growth of certain seaweeds and sea grass;
- changes in species composition and dominance;
- societal and economic impacts; and
- other potential impacts that presently remain unknown.

In the East Coast region, monitoring in the Gulf of St. Lawrence indicates that there has been no significant change in the pH of surface waters since 1934 (DFO, 2012a). In the St. Lawrence estuary, waters at greater than 100 m depth are acidifying faster than the surface waters because of *in situ* processes; this trend is not directly related to increased greenhouse gas emissions (Scarratt and Starr, 2012). In the Scotian Shelf area, pH has declined by about 0.1–0.2 units since the early 1930s (Stewart and White, 2001).

Many commercially important shellfish species harvested in Nova Scotia, such as the American lobster (*Homarus americanus*) and Atlantic deep-sea scallop (*Placopecten magellanicus*), and many aquaculture species, such as the blue mussel (*Mytilus edulis*), American oyster (*Crassostrea virginica*) and quahog clam (*Mercenaria mercenaria*), are vulnerable to acidification during the fertilization, cleavage, larval settlement and reproduction stages (Curren and Azetsu-Scott, 2013).

4.4 SALINITY

Records of ocean salinity for some areas of the East Coast region are available from the late 1940s, enabling calculation of decadal variability. Since the 1960s, for example, the Scotian Shelf area has seen oscillating periods of cold, fresh water (1960s, 1980s, 1990s) and warm, more saline water (1970s and 2000s; Breeze et al., 2002). The 1990 decadal mean surface salinities for the Gulf of St. Lawrence, the Scotian Shelf and the Bay of Fundy were the lowest ever recorded (Drinkwater and Gilbert, 2004).

Recent studies have reported a further decrease in salinity (freshening of water) off the coast of Nova Scotia (Scotian Shelf and Gulf of Maine; Drinkwater and Gilbert, 2004; Greene et al., 2008), potentially resulting from the melting of Arctic sea ice. As Arctic sea ice continues to melt in the future, the resulting pulses of fresh water will increase the strength of the southward-flowing Labrador Current and reduce sea-surface salinity. This could result in biogeographic changes of some species, such as was documented for the boreal plankton *Neodenticula seminae*, which is now common in the North Atlantic flora (Greene et al., 2008). Based on sedimentary records, this Pacific Ocean plankton species had not been present in the East Coast region for 800 000 years (Nye, 2010).

Under climate change, it is projected that the North Atlantic Oscillation (NAO; *see* Chapter 2) will be dominantly in a positive phase, shifting the warmer water of the Gulf Stream northward and increasing the volume of cold water transported by the Labrador Current (Frumhoff et al., 2007). A projected decrease in annual outflow from the Great Lakes watershed will also impact the circulation and salinity of the Gulf of St. Lawrence (Dufour and Ouellet, 2007).

Organisms can respond in several ways to these changes in temperature and salinity, but a shift in spatial distribution is the hypothesized first response (Nye, 2010). The responses of natural ecosystems are likely to be nonlinear, such that change may not occur until a threshold has been reached, at which time rapid, dramatic transitions may be expected (Dufour and Ouellet, 2007).

4.5 WATER QUALITY

Coastal water quality affects many parameters that govern the overall health and functioning of marine ecosystems (Burbridge, 2012). Water quality could suffer in areas experiencing increases in rainfall. For example, heavy precipitation events can cause problems for water infrastructure, as sewer systems and water-treatment plants can be overwhelmed by the increased volume of water. Heavy downpours can also increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste and other materials into water supplies, making them unusable, unsafe or in need of additional water treatment.

In the East Coast region, there has been no systematic monitoring of coastal-water quality that would enable a spatial or trend analysis of the quality of coastal marine waters (Burbridge, 2012) and possible linkages to climate change versus other human activities. Apart from data required to determine the safe levels of specified contaminants found in fish, shellfish and fish products (Stewart and White, 2001; Simms, 2002), water quality in nearshore coastal environments remains largely unknown (Mercer Clarke, 2010). Contaminant concentrations in water, sediments and/or biota have been measured in a number of provincial harbours and estuaries, as well as in the open waters of the Scotian Shelf, the Bay of Fundy and the Gulf of St. Lawrence. For most open-water sampling sites, contaminant concentrations are low (i.e., at or near background concentrations) and there is little or no indication that environmental harm can be attributed to the contaminants (CBCL Limited, 2009). Contamination has been documented at sites in proximity to urban and industrialized centres, such as Halifax Harbour, NS; Sydney Harbour, NS; Strait of Canso, NS; Clam Harbour, NS; and the area of Belledune, NB.

4.6 SALTWATER INTRUSION

Saltwater intrusion is the infiltration and mixing of seawater with fresh water stored in the pores and fractures of the underlying soil and bedrock of coastal lands. The seawater–fresh-water interface is naturally dynamic and fluctuates in response to changes in recharge, withdrawals and sea level. Displacement of fresh water by seawater occurs as seawater moves inland as a result of sea-level rise, storm surge, coastal erosion or prolonged dry periods (Phan, 2011; Loaiciga et al., 2012).

Saltwater intrusion is expected to become a more prominent issue as a result of climate change, although increasing demand for groundwater resources will be a more important driver than sea-level rise. Warmer summers are likely to lead to increased withdrawals of groundwater (Government of Prince Edward Island, 2011), particularly if this is associated with increased tourist demand. Although sea-level rise increases the risk of seawater intrusion and well contamination, the extent of this increase is not well understood (Chang et al., 2011). Increased coastal flooding associated with sea-level rise and storm surges could contaminate potable-water wells with saltwater.

A large proportion of the population of the East Coast region (nearly 100% in the case of Prince Edward Island and the Îles de la Madeleine) relies on groundwater for potable water (Rivard et al., 2008). Examples of groundwater impacts associated with natural and/or human factors are documented for every province in the East Coast region:

- **New Brunswick:** Shippagan and Richibucto (due to overpumping; MacQuarrie et al., 2012); many private wells are intermittently contaminated by seawater during storm surges in Le Goulet
- **Nova Scotia:** Upper Lawrencetown and Pictou (due to development and increased groundwater demand); Pugwash and Wolfville (Ferguson and Beebe, 2012)
- **Prince Edward Island:** Summerside (due to overpumping; Hansen, 2012); York Point and Souris West (caused by natural saltwater intrusion); Prince Edward Island is particularly vulnerable to saltwater intrusion because of its geography and dependence on groundwater for potable water (Barlow and Reichard, 2010)
- **Newfoundland and Labrador:** saltwater intrusion is well documented in L'Anse-aux-Meadows (N. Catto, personal communication, 2014); the extent of saltwater intrusion at a provincial level cannot be confirmed (Adams, 2011)
- **Quebec:** there is no documented saltwater intrusion, but drawdown saltwater cones exist beneath some wells on the Îles de la Madeleine and a migration of the saltwater interface has been reported for the Île du Cap aux Meules in the Îles de la Madeleine (Chaillou et al., 2012a, b); the Îles de la Madeleine archipelago is solely dependent on groundwater resources for its water consumption and is highly vulnerable to overpumping, particularly in summer when visitor traffic currently doubles the local population.

4.7 EFFECTS ON ECOSYSTEMS

Changes in environmental conditions often result in a shift in spatial distribution of species and ecosystems (Walther et al., 2002; Parmesan and Yohe, 2003). As waters warm, for example, populations of mobile marine organisms can change spatially as the area of favourable habitats changes (Section 4.1). This seems to have been the case for some fish species of the East Coast region during the late 1980s and early 1990s, when northern cod and capelin were detected in the northwest Atlantic (Rose et al., 2000). A study of fish stocks off the coasts of North America showed that 72% of fish species shifted their overall centre of biomass northward and increased their average depth of occurrence during the period 1968 to 2007 (Cheung et al., 2011). The temperature at which these species have been found over those same 40 years has not changed (Nye, 2010), suggesting that fish are maintaining their preferred ambient temperature range by moving to higher latitudes or to deeper waters. Distributions of some northeast Atlantic species are projected to shift northward at an average rate of around 40 km per decade (Cheung et al., 2009). Projections of changes in species distribution as a result of climate change for the Gulf of St. Lawrence and the Atlantic coasts suggest that there could be a high turnover in species (i.e., many losses and many gains; Cheung et al., 2011). Differential species responses to climate change are likely to lead to trophic mismatches and/or perturbed prey-predator relationships, breaking the ecological equilibrium and leading to community reassembly (Walther et al., 2002; Beaugrand et al., 2003; Edwards and Richardson, 2004; Collie et al., 2008).

Table 4 presents the major anticipated effects on habitats in the East Coast region arising from sea-level rise and changing storm patterns. Within intertidal areas, rising temperatures will affect different beach ecosystem components. For many beach species, range extension will be a limiting factor due to the lack of dispersal capabilities at the larval stage (peracarid crustaceans), while changes in plankton communities will also impact beach macrofauna (i.e., peracarids and insects; Defeo et al., 2009).

4.8 MIGRATION OF ECOSYSTEMS AND COASTAL SQUEEZE

Coastal ecosystems dynamically adjust to changes in sea level. Field observations, including *in situ* tree stumps and roots, and fresh-water peat layers exposed at low tide or after storm events at numerous locations (Figure 9), provide evidence of the migration of coastal ecosystems due to relative sea-level rise in the past 6000 years (e.g., Garneau, 1998; Quintin, 2010).

Beaches, dunes, sand spits, barrier islands and their associated coastal marshes can adjust to increasing sea levels by continuous landward migration (Davidson-Arnott, 2005). In sandy environments, landward migration is achieved through overtopping (where waves surmount a beach crest but do not erode it, gradually adding sediments to the crest), breaching and overwash (waves surmount and erode the beach crest, depositing sediments farther landward), tidal-inlet development (leading to the formation of tidal deltas) and wind action (strong offshore winds transporting sand in the backdune and in the marsh or lagoon; Taylor et al., 2008; Jolicoeur et al., 2010; Mathew et al., 2010; Stéphan et al., 2010; Ollerhead et al., 2013). This process, which is strongly related to storms, allows sandy features to move landward and adjust vertically as sea level rises. However, high rates of relative sea-level rise can result in drowning of coastal landforms (O'Carroll et al., 2006; Kelley et al., 2013).

FIGURE 9: Photos of *in situ* tree stumps exposed at low tide or after storm events. Photos **a)** and **b)** shows tree stumps and roots that have been uncovered by erosion and **c)** shows tree stumps that been submerged by rising water levels. Locations of photos: **a)** Le Goulet, NB; **b)** Barachois, NB; and **c)** Bras d'Or Lakes, NS. *Photos a) and b) courtesy of D. Bérubé, Department of Energy and Mines New Brunswick, and photo c) courtesy of S. O'Carroll, Geo Littoral Consultants.*

TABLE 4: Projected impacts of climate change related to sea-level rise and changes in storm patterns on the coastal habitats of the East Coast region (*adapted from* Nye, 2010).

Coastal feature	Impacts
Beaches	Large-scale morphological adjustments to absorb the wave energy, including: ▪ overwash and erosion ▪ potential formation of new beaches down-drift of erosion areas ▪ landward migration of barrier beaches
Salt marshes	More frequent tidal flooding Sedimentation and possible landward migration at a rate equal to sea-level rise, depending on sediment and organic matter supply Increased margin-edge erosion (van Proosdij et al., 2006) Changes in carbon storage (Chmura, 2011)
Fresh-water marshes	Gradually become salt marshes or migrate inland
Estuaries and tidal rivers	Increased tidal volume and exchange Further penetration of saltwater
Unconsolidated cliffs	Accelerated erosion
Species and ecosystems	Modification of coastal habitats Threatened viability from changes in numerous factors, including water temperature, salinity, sea-ice patterns, runoff and water quality

In coastal marshes, fine-grained material deposited on, and/or organic matter produced in, the marsh raises the surface, keeping it in the same position relative to sea level (Allen, 2000). Gradually, a transition from low-marsh to high-marsh vegetative communities evolves and, in ideal settings, the marsh migrates landward. Again, if sea level rises faster than the sediments can be supplied, marshes can be flooded and replaced by open water, as was observed in southeastern New Brunswick between 1944 and 2001 (Hanson et al., 2006). Changes in sediment supply will also affect marsh survival. Kirwan and Megonigal (2013) demonstrated that, under moderately rapid sea-level rise, a marsh that is stable under historical sediment loads would submerge if the sediment load is reduced. This suggests that dam construction and land construction that result in the reduction of sediment load could cause marshes to become less stable in the future, even if the rate of sea-level rise were to remain constant.

Marshes developed in areas of high tidal range and high sediment availability are generally considered more resilient to sea-level rise than those developed in areas of low tidal range and low sediment availability (Chmura et al., 2001; Paskoff et al., 2011; Bowron et al., 2012). In the East Coast region, historical rates of salt-marsh aggradation range from 1.3 mm/year along the Northumberland Strait coast of New Brunswick to 4.4 mm/year in the upper reaches of the Bay of Fundy (Chmura et al., 2001; Davidson-Arnott et al., 2002; van Proosdij et al., 2006; Bowron et al., 2012). Along the St. Lawrence estuary, average vertical accretion rates range from 1 to 2 mm/year, and as high as 3 mm/year in about 10% of cases (Dionne, 2004).

Vertical accretion rates can adjust to changes in the rate of relative sea-level rise (Kirwan et al., 2010). While cyclicity in edge erosion and progradation is part of natural marsh evolution at the decadal scale (Allen, 2000; Ollerhead et al., 2006; van Proosdij et al., 2006; van Proosdij and Baker, 2007; Allen and Haslett 2014), marshes will migrate landward if there is space for them. However, retreat cannot occur where natural slopes behind the marsh are too steep, or where the path is blocked by structures such as roads, seawalls, dikes or buildings, creating a situation known as 'coastal squeeze' (Figure 10; Doody, 2013; Pontee, 2013; Torio and Chmura, 2013).

Coastal squeeze is not exclusive to coastal marshes but can also apply to other types of coastal ecosystems (e.g., beaches, dunes) and includes natural constraints, such as cliffs, that may limit landward migration (Figure 10c; Sterr, 2008; Jackson and McIlvenny, 2011; Doody, 2013; Hapke et al., 2013). In the East Coast region, studies in the Baie des Chaleurs, NB (Bernatchez and Fraser, 2012) and in the Îles de la Madeleine, QC (Jolicoeur and O'Carroll, 2007) have shown that the presence of human infrastructure is causing the loss of coastal habitats. In the Baie de Kamouraska, QC, dikes constructed to convert marsh into farmland are squeezing the intertidal zone as sea level rises. Increasing development of the coastal zone across the region increases coastal squeeze and could lead to loss of valuable marshes, dunes and beaches in coming decades (Jolicoeur and O'Carroll, 2007; Craft et al., 2009; Bernatchez et al., 2010; Feagin et al., 2010; Doody, 2013; Torio and Chmura, 2013; Cooper and Pile, 2014).

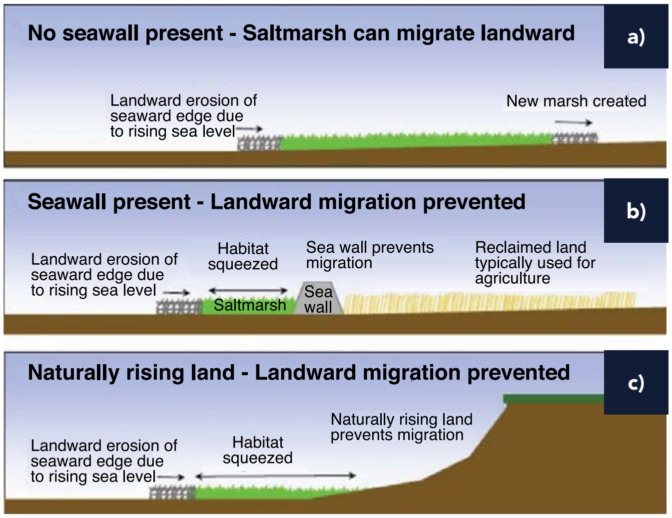

FIGURE 10: Illustration of the landward migration and prevented landward migration of coastal habitat that has been eroded by rising sea level: **a)** landward migration occurs naturally, **b)** migration has been prevented by a sea wall resulting in the 'squeeze' of habitat, and **c)** migration has been prevented by naturally rising land resulting in the 'squeeze' of habitat (Pontee, 2013 *adapted from* Doody, 2013).

4.9 IMPACTS OF HUMAN ALTERATIONS ON THE COAST

Human activities leading to changes in land use, watercourses and shorelines have already impacted nutrient and contaminant runoff, storm-water management and water quality in areas of the East Coast region. Shoreline hardening with various protection methods (walls, rip-rap, dikes, groins, pavements and landfill) and dredging have altered coastal circulation patterns and sediment transport, potentially exacerbating shoreline erosion and reducing the ability to attenuate flooding (Section 6.3.4; e.g., Hapke et al., 2013; Pontee, 2013). Changes to land cover can destroy or impair native-species habitats (Ban and Alder, 2008; Halpern et al., 2008; Burkett and Davidson, 2012). The use of hard engineering measures to protect societal assets can lead to the loss of intertidal sand habitat (Defeo et al., 2009; Leclerc, 2010; Bernatchez and Frazer, 2012; Spalding et al., 2014). Measures that promote the resilience of coastal areas include protection, revegetation and stabilization of dunes; maintenance of sediment supply; and provision of buffer zones, rolling easements or setbacks that allow landward migration of the coastline (*see* Chapter 3; Defeo et al., 2009).

Understanding how, and to what degree, a coastal system will be modified by climate change remains a challenge, given the complex interrelationship between natural and human systems. This is highly evident within the extensively diked estuaries of the Bay of Fundy, where many of the main rivers draining into the bay have been fully or partially obstructed (van Proosdij and Page, 2012). An engineering structure, such as a dike, that reduces the extent of tidal flooding, a structure that decreases the cross-sectional area of a channel or the closure of a section of an estuary will, as a consequence, change the magnitude of the characteristic tidal discharge (van Proosdij and Baker, 2007; van Proosdij et al., 2009). This can lead, in turn, to rapid sedimentation and/or alteration of the intertidal morphology of the estuary and position of intertidal habitat. The response of the system, however, depends on a large number of factors, including sediment properties, estuary morphology and the timing and sequence of engineering alterations (*see* van Proosdij et al., 2009 for comparison of Petitcodiac River, NB to Avon River, NS).

5 COMMUNITIES AND ECONOMIC SECTORS

Coastal communities and economic activity in the East Coast region will be affected by the climate-related changes described in Sections 3 and 4, especially those associated with coastal hazards, including erosion and storm-surge flooding (Hughes and Brundit, 1992; Arkema et al., 2013). The impacts associated with climate change reflect both the degree of exposure to natural hazards and the vulnerability of the system exposed (Figures 11, 12). Vulnerability, or the predisposition to be adversely affected, encompasses a variety of elements, including sensitivity to harm and the capacity to cope with changes or to adapt to them (*see* Chapter 1, Box 4 for definitions of key terms). Adaptive capacity is influenced by access to resources, as well as important social factors. Adaptation actions are undertaken with the goal of reducing risks or taking advantage of opportunities. However, many human alterations to the coast have proven to be maladaptive in that they affect coastal processes in ways that increase the vulnerability of coastal ecosystems, communities and infrastructure.

This section examines the concepts of exposure, sensitivity and capacity to adapt, using examples from the East Coast region. It then provides an overview of recent initiatives to document vulnerabilities, and highlights climate change impacts as they relate to key economic activities (e.g., fisheries, transportation and tourism) and community health, well-being, culture and heritage.

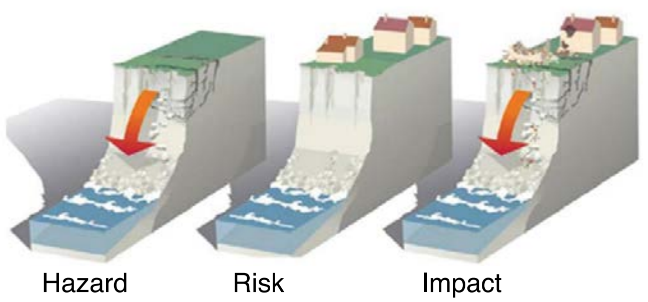

FIGURE 11: Coastal hazards, risks associated with exposure of valued assets (including ecosystem services) and impacts (*adapted from* Ministère de l'Écologie et du Développement durable de France, 2004).

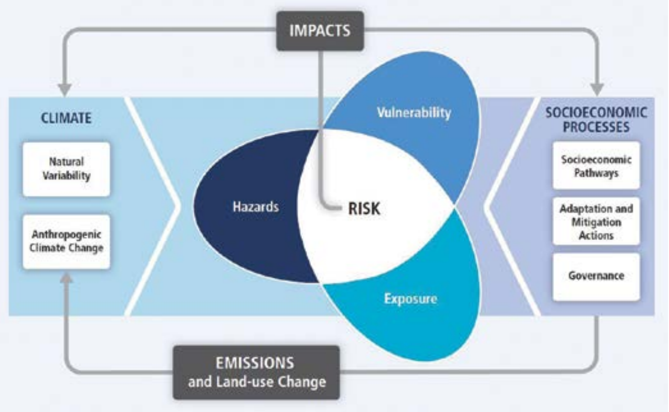

FIGURE 12: Climate impacts associated with coastal risks result from the interaction of coastal hazards and the vulnerability of exposed systems (*from* IPCC, 2014).

5.1 EXPOSURE

Exposure refers to the presence, in places and settings that could be adversely affected, of people; livelihoods; species or ecosystems; environmental functions; resources; infrastructure; or economic, social or cultural assets (IPCC, 2014). In coastal areas, exposure is influenced by physical attributes or characteristics of the coastal zone and is directly related to the likelihood that hazardous conditions will occur (Dolan and Walker, 2006; Tibbetts and van Proosdij, 2013). Settlements on a former low-lying marshland or eroding coastal bluff are more exposed to risks related to the impacts of sea-level rise, storm surge and accelerated erosion than are settlements located above the higher high tide water level or on resistant bedrock.

Exposure is often associated with the amount of wave energy reaching the coast. It is influenced by the orientation of the shoreline relative to wind and wave action, as well as features that decrease the amount of energy reaching the shoreline, such as shorefast ice, offshore sea ice, intertidal vegetation and nearshore bars. The direction of the most damaging waves varies throughout the East Coast region.

For example, winds in Prince Edward Island are mainly from the west, but the largest waves are generally from a north-northwesterly direction (Davies, 2011). In northern New Brunswick, local residents say that the most damaging wind and waves come from the northeast and refer to these winds and associated violent storms as 'les nordets' (O'Carroll, 2008). In western parts of Cape Breton, NS, damaging local winds are known as 'les suètes' and are created when a frontal inversion causes a funnelling effect over the Cape Breton Highlands. As the winds rush down the side of the highlands, strong gusts develop; these have been recorded to exceed 150 km/h.

With some exceptions, communities lying on coastlines exposed to the full swell and storm waves from the Atlantic Ocean receive the most wave energy. Wave climate and associated exposure varies throughout the year (Dufour and Ouellet, 2007) and between years (Davies, 2011). For example, the north shore of Prince Edward Island shows strong interdecadal variability, with the period 2000–2009 having more wave energy than any other decade since the 1960s (Davies, 2011). This relates, in part, to ice cover, which decreased from a mean of 103 days in the 1970s to a mean of 80 days in the 2000s (Davies, 2011) along the same shoreline.

Another factor influencing exposure is tidal range, which varies significantly across the East Coast region, from less than a metre near the Îles de la Madeleine to more than 16m in Cobequid Bay on the Bay of Fundy (e.g., Cooper and McLaughlin, 1998; Boruff et al., 2005; Rao Nageswara et al., 2008; Kumar et al., 2010; Pendleton et al., 2010; Tibbetts and van Proosdij, 2013). Coastal systems in areas with a small tidal range (microtidal) are generally less able to accommodate extreme water levels associated with storm surge, as there is a smaller area available to absorb the surge. In addition, since a storm surge would have greatest impact when it occurs at or near the high-tide level, the likelihood of damaging surge events is lower for areas with a large tidal range (macrotidal; Desplanque and Mossman, 2004).

The most common factors that reduce the flow of wave energy to coasts in the East Coast region are offshore sea ice (Section 3.3), shorefast ice (e.g., Northumberland Strait coast, Gulf of St. Lawrence, Newfoundland), sea-grass beds (e.g., Port Joli harbour, NS), foreshore marsh (salt marshes developed seaward of a dike structure; e.g., Minas Basin, NS) or dunes (e.g., north shore of Prince Edward Island), and beach barriers (e.g., spit in Bouctouche, NB or gravel barachois [coastal lagoon separated from the ocean by a sand or shingle bar] in Newfoundland). For example, coastal wave energy on the northeast coast of the island of Newfoundland can be largely muted once offshore ice cover develops, but coastlines along the southern side of the island remain vulnerable to erosion by winter storms (Taylor et al., 1997; Forbes et al., 2000; Ingram, 2004; Catto, 2011). Foreshore marshes are capable of attenuating up to 97% of incoming wave energy, depending on the size of the marsh (Möller and Spencer, 2002; Doody, 2008; van Proosdij and Page, 2012; Möller et al., 2014). Preservation and/or encouragement of foreshore-marsh habitat are examples of adaptation measures that aim to enhance and/or restore ecological processes to help decrease environmental impacts from built infrastructure (Chapman and Underwood, 2011; van Proosdij and Page, 2012).

5.2 SENSITIVITY

Sensitivity is the degree to which a system (e.g., ecosystem, community, infrastructure) is affected, either adversely or beneficially, by climate-related changes (IPCC, 2014) and is related to both the severity of the exposure and the potential consequences. Coastal settlements can be differentially sensitive to climatic risks, depending on their socio-economic and cultural characteristics, and their planning and operational structures.

Historical European settlement patterns in the East Coast region were driven largely by the need to access or transport resources such as fish, ore and wood, so infrastructure like warehouses and roads were built along or close to the shore. Throughout much of the region, communities had their beginnings providing homeports and infrastructure in support of inshore and offshore fisheries. Coastal villages were initially linked by boat transport and, when roads were built, they followed the historical pattern. Throughout French-Acadian Nova Scotia, extensive dike systems were constructed by early settlers to drain fertile salt marshes for agriculture purposes. Major ports constructed in Saint John, NB, Halifax, NS, St. Johns, NL and Québec, QC evolved to continue trade links with eastern North America and Europe.

Sensitivity to climate impacts is influenced, in part, by the persistence of these early settlement patterns despite the fact that, in some cases, contemporary industries bear little resemblance to activities of the past. This is particularly notable in diked marshlands, which were formerly harvested for highly valued salt-marsh hay (Lieske, 2012). For example, the Chignecto Isthmus region (which joins the provinces of Nova Scotia and New Brunswick) underwent a shift from a major hay-production centre to a critical transportation and communications corridor that annually moves $43 billion worth of international trade goods. Yet infrastructure throughout many of the towns and villages in the region continues to rely on approximately 33 km of the early agricultural dikes for protection against the rising tides

(Webster et al., 2012b; Wilson et al., 2012). A once-in-10-years storm surge could overtop approximately 90% of the existing dike system and temporarily inundate 20% of the Town of Sackville, NB (Lieske and Bornemann, 2012).

Contemporary development patterns are also influenced by tourism and recreation opportunities, such as cottages and seasonal rentals close to the coast. The small chalets and cabins that were once people's secondary residence are now often modified to become principal homes. This is evident along most shores of the East Coast region, particularly along the shores of Northumberland Strait, the north shore of Prince Edward Island and the southern shores of Nova Scotia. These changes significantly increase the asset value at risk from coastal hazards (Delusca et al., 2008), not only in terms of absolute dollars but also because different levels of risk are tolerated for secondary and principal residences.

Sensitivity is also related to the degree to which the hazard impacts areas of environmental, social, economic and cultural significance. For example, a community that becomes isolated from emergency services when its only transportation link has been flooded or destroyed is more sensitive than one that has more options for access to services and/or evacuation. This was illustrated in 2010, when rainfall associated with Hurricane Igor washed out roads and bridges across the Burin and Bonavista peninsulas of Newfoundland. Sensitivity is also influenced by social conditions (i.e., income, age and education), community resources and social structures (Dolan and Walker, 2006; Garmendia et al., 2010; Rapaport et al., 2013). In some areas of the East Coast region, the aging rural population and their greater sensitivity to direct (e.g., flooding and excessive heat) and indirect (e.g., inability to access social support, food and medical care) climate stressors is a particular concern (Rapaport et al., 2013). Other considerations with respect to economic sensitivity include possible impacts of extreme weather events on employment and industrial infrastructure.

5.3 CAPACITY TO ADAPT

Adaptive capacity refers to the ability of a country, region, community or group to implement effective adaptation measures (e.g., IPCC, 2007; Lemmen et al., 2008). It is influenced by a large number of social, economic, regulatory and political factors (e.g., Smithers and Smit, 1997). As change becomes more rapid, the adaptive capacity of many communities may be challenged. Extreme impacts can exceed human and financial resources to address them, and can cause physical, financial and psychological stress. Stress on local governments and service providers, and other responders to disasters, can reduce adaptive capacity to address climate change impacts in both the short and long terms (Manuel et al., 2012).

Within the East Coast region, there has been a surge in provincial and local government initiatives and community-university research partnerships during the past decade, all focused on improving adaptive capacity and moving forward on adaptation planning for climate change. For example, 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 better prepare for, and adapt to, climate change (Atlantic Climate Adaptation Solutions Association, 2012). In Quebec, Ouranos, a joint initiative of the Government of Québec, Hydro-Québec and Environment Canada, with the financial support of Valorisation-Recherche Québec, was created as a consortium on regional climatology and adaptation to climate change and has brought together more than 400 scientists and professionals from across relevant disciplines.

Numerous initiatives have been undertaken in recent years throughout the East Coast region to develop practical tools for adaptation planning (*see* Chapter 3) and to incentivize adaptation action (Case Study 3). Many smaller communities with limited resources have benefited by collaborating with universities and colleges across the region that can provide expertise and technological innovations (e.g., Bernatchez et al., 2008a; Fedak, 2012; Lieske, 2012; Manuel et al., 2012).

CASE STUDY 3

FINANCIAL INCENTIVE FOR ADAPTATION PLANNING: THE MUNICIPAL CLIMATE CHANGE ACTION PLAN OF NOVA SCOTIA

The federal government transfers funds equivalent to a portion of the federal excise tax on gasoline to municipalities for infrastructure projects that contribute to cleaner water, cleaner air and/or reduced greenhouse-gas emissions. In Nova Scotia, terms and conditions for 'gas tax' eligibility are defined in the Canada–Nova Scotia Agreement on the Transfer of Federal Gas Tax Funds. As a requirement for funding, Nova Scotia municipalities had to submit a Municipal Climate Change Action Plan (MCCAP) by the end of 2013. The MCCAP has served as a means of identifying priority areas for adaptive action.

Service Nova Scotia and Municipal Relations, and the Canada–Nova Scotia Infrastructure Secretariat provided a guidebook (Fisher, 2011) that outlines a six-step framework to assist municipalities with the adaptation portion of MCCAP development. Each step consists of a series of questions that, cumulatively, assess if and how local climate trends and projections would introduce or exacerbate hazards, and in what ways these changing conditions may affect people's safety, municipal services and assets, and other community characteristics (e.g., local economic functions, sense of place and community well-being, emergency preparedness planning and capacity for response).

A key to successful MCCAP development for all municipalities in Nova Scotia was the document *Scenarios and Guidance for Adaptation to Climate Change and Sea Level Rise – NS and PEI Municipalities* (Richards and Daigle, 2011), which provided a common starting point with respect to climate trends and projections. Beyond this foundation document, the quality of an MCCAP was defined largely by a municipality's internal capability to interpret climate trends and projections in a local context, in order to understand what impacts are likely and the potential severity of their consequences.

A recent survey of municipal climate change adaptation around the Bay of Fundy indicated that a combination of factors, including limited staff time and expertise, stretched budgets and lack of jurisdictional authority, make it difficult for municipalities to address even well-documented vulnerabilities to climate change (Schauffler, 2014). The MCCAP process highlighted several findings, including that key factors such as geology are often excluded in land-use planning decisions. In large part, this is a reflection of the high daily demands placed on the land-use– and community-planning sector, and the lack of support to seek out and include additional information when developing long-term land-use strategies. Other challenges highlighted by the MCCAP process include the following:

- The limited jurisdiction of municipalities makes it difficult to address some key climate risks. For example, private wells are controlled provincially. Therefore, although a community may experience significant social and economic impacts from wells going dry, it is not involved in groundwater monitoring, management or well permitting. In addition, there are a number of issues (e.g., extension of water services) that fall under provincial jurisdiction where municipal units could play a greater role in shaping regional responses to climate change adaptation.
- Some of the scientific and technical information that municipalities sought was unavailable or not easily accessible. The MCCAP process highlighted what information or tools are helpful for municipalities to enhance climate resilience, and raised the question of who should be responsible for the collection and dissemination of that information. As municipalities do not have experts in coastal processes on staff, they must seek external expertise if, for example, erosion is an issue worthy of investigation.

Despite these challenges, the Nova Scotia MCCAP process can be considered a success in many ways. For example, the inclusion of emergency-management personnel on municipal climate change committees and the collaborative assessment processes renewed recognition of the relationship between land use and disaster-risk reduction and response. This prompted improvements in information exchange (i.e., mapping) and collaboration between these two facets of municipal management.

Municipalities generally came to a shared conclusion that they had an important role to play in helping residents manage their own risk by sharing what was learned about climate risks during the MCCAP process. Simultaneously, judgments were made as to when providing information may prove insufficient, and when policy is needed to control development with the aim of reducing risks. It was also recognized that seldom will 'one-size-fits-all' policies work when addressing coastal hazards, so site-specific work is needed to balance a municipal responsibility to respond to known (or suspected) risk and the desire to allow appropriate use of a property. The MCCAP process has led to notable progress at the provincial level to organize, improve upon and disseminate relevant data to municipalities.

By requiring that MCCAPs consider social and economic climate impacts, there has been a subtle yet profound shift from climate-adaptation planning being considered a one-off research topic to it becoming a process through which a municipal corporation actively gauges trends in external forces (i.e., macroeconomics, demographics, health and governance) in combination with honest self-evaluation. This is an approach that provides benefits no matter how the climate unfolds.

Advances in technology and an increased ability to translate data into knowledge have increased adaptive capacity across the East Coast region. High-resolution LIDAR (Light Detection and Ranging) topographic surveys and advanced geographic information systems have enabled inundation studies at many sites in the East Coast region (e.g., Daigle, 2006; Robichaud et al., 2011; Fedak and van Proosdij, 2012; Webster et al., 2012a; Lieske et al., 2014; Daigle et al., 2015). Effective identification of hazard areas for planning purposes has also been conducted with coarser, digital elevation models (e.g., Isle Madame, St. Margarets Bay, Cape Breton and parts of the south coast of Nova Scotia; Lane et al., 2013; Rapaport et al., 2013).

5.4 VULNERABILITY ASSESSMENTS

During the past decade, there has been a significant increase in the number of vulnerability assessments performed in the East Coast region, most in the form of technical reports. In developing this chapter, 226 individual studies conducted since the late 1990s were inventoried for the East Coast region. Many of these studies covered more than one community. The studies were grouped in broad categories in order to paint a picture of the work carried out and the focus of research so far (Figure 13). Note that the inventory is limited to publicly and readily accessible documents, and is therefore not exhaustive.

Of the studies compiled, more than 40% of those conducted in Prince Edward Island, Quebec and New Brunswick focused on coastal erosion. Vulnerability and ecosystem restoration studies are prominent in Nova Scotia, with special reference to the MCCAPs and the extensive diked areas of the province. In Newfoundland and Labrador, flooding dominated the literature examined (60%). It should be noted that the extensive province-wide assessments of erosion by Catto (2011) and Webster (2012) in Newfoundland and Prince Edward Island, respectively, are likely not adequately represented in this analysis.

Areas where communities currently lack significant assessment, such as the eastern shore of Nova Scotia, the mid-Fundy shore of New Brunswick, much of Newfoundland and Labrador, and the Quebec North Shore, are evident in Figure 13. Addressing some of these gaps may be assisted by increased accessibility of public data. For example, the New Brunswick Government is in the process of making its Coastal Erosion Databank public, so that more than 14 500 erosion rates will be accessible online via an interactive map (D. Bérubé, personal communication, 2015). Erosion data for Newfoundland and Labrador will also soon be available online as an interactive map (N. Catto, personal communication, 2015).

Although there are multiple methods for assessing coastal vulnerability, the most common methods utilize indices that simplify a number of key parameters to create a single indicator (Carrasco et al., 2012). The earliest studies of coastal vulnerability were based largely on biophysical characteristics, defining vulnerability in terms of exposure to a hazardous event regardless of impacts on social conditions (Abraham et al., 1997; Dolan and Walker, 2006). This approach has been commonly used in the East Coast region with a primary focus on coastal erosion and flooding due to sea-level rise and/or storm surge. In limited areas, two- and three-dimensional hydrodynamic modelling studies have been performed to assess the velocity of flood water versus depth (e.g., Wolfville, NS; Fedak, 2012; van Proosdij, 2013), the coupled effect of fresh-water drainage and tidal surge in an estuarine area (e.g., Oxford and River Philip, NS; Webster et al., 2012b) and the effect of wave run-up (e.g., Halifax Harbour, NS; Xu and Perrie, 2012).

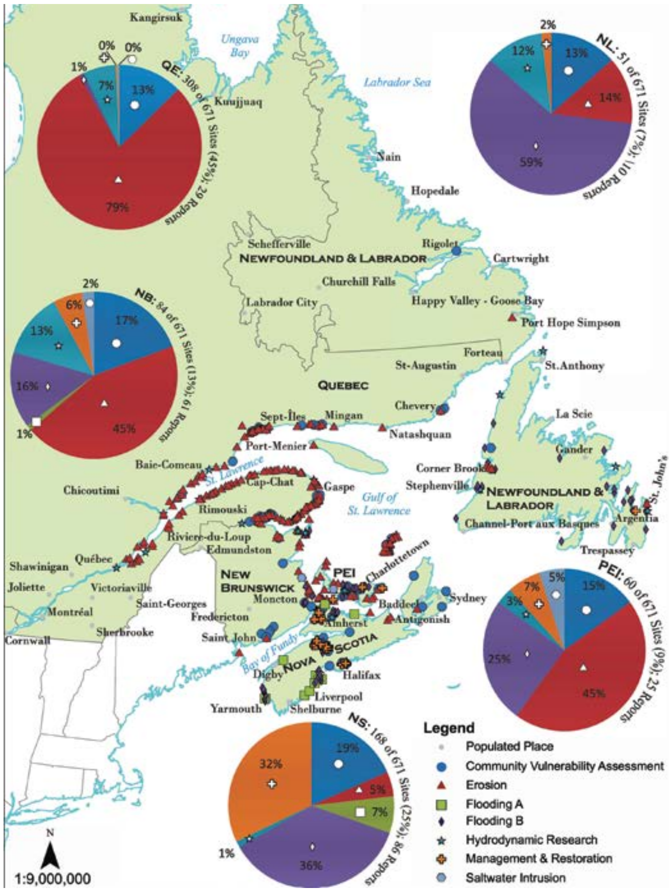

FIGURE 13: Spatial compendium of sites examined through vulnerability studies in the East Coast region. Legend categories include community vulnerability assessments, erosion (rate, shoreline adjustment, geological studies), flooding A (general extent with SLR), flooding B (SLR and/or storm surge with infrastructure and/or social variables), hydrodynamic (1-D and 2-D models and scenarios), management and restoration (shoreline restoration and management/policy assessments), and saltwater intrusion (intrusion or transition studies). The inventory was limited to publicly and readily accessible documents, and is therefore not exhaustive. Compendium compiled by B. MacIsaac and cartography by B. Perrott (Maritime Provinces Spatial Analysis Research Centre, Saint Mary's University).

Coastal erosion indices have been produced for the entire coasts of the island of Newfoundland (Catto, 2011), the North Shore of the Gulf of St. Lawrence (Dubois et al., 2005), the Îles de la Madeleine (Bernatchez et al., 2012b), New Brunswick (O'Carroll et al., 2006; O'Carroll, 2008) and Prince Edward Island (O'Carroll, 2010b; Webster, 2012). Smaller, geographically focused studies of rates of coastal erosion have been conducted in Nova Scotia (Fink, 2007; Utting and Gallacher, 2009; Force, 2012), Quebec and New Brunswick (Section 3.4). Catto (2012) has advocated the differentiation of long-term (e.g., sea-level rise) versus short-term (e.g., episodic storms) drivers of coastal erosion.

Individual events, such as the January 2000 storm that impacted southwestern and southern Newfoundland (Forbes et al., 2000; Catto et al., 2006) and Hurricane Igor in 2010 (Catto, 2011), can result in extensive coastal erosion unrelated to sea-level rise or other long-term changes. Other studies that have documented significant morphological changes in response to storm conditions include those of post-tropical storm Noel (Taylor et al., 2008) and the surge associated with a February 2013 blizzard in Nova Scotia (Taylor, 2014).

With respect to future rates of change in shoreline position, most studies make inferences based on historical analyses and assume a linear relationship. Alternative approaches include those applied to Prince Edward Island, in which erosion rates and shoreline position were based on computer analyses of longshore transport within littoral cells and the derivation of a coastal-sediment budget per cell (*see* Chapter 2; Davies, 2011). This approach permits consideration of seasonal cyclicity and movement of sediment within each cell. MacDonald (2014) incorporated these processes to document changes in physical coastal vulnerability over time as the position of the coastline changes. An economic assessment of the impacts of erosion on the coastal infrastructure in Quebec revealed that, by the year 2065, 5426 buildings will be exposed to erosion if no adaptation measures are undertaken (83% of these buildings being dwellings), and 294 km of roads and 26 km of railroads will likewise be exposed. The combined value of this infrastructure is 1.5 billion dollars (Bernatchez et al., 2015).

Studies focused on the physical effects of erosion and/or inundation on residential, commercial and institutional infrastructure include those initiated in response to concerns in the communities of Le Goulet, Shippagan and Bas-Caraquet in northeastern New Brunswick, that were seeking detailed information on storm-surge levels and coastal-erosion maps to aid in the development of municipal plans (Robichaud et al., 2011; Aubé and Kocyla, 2012; Jolicoeur and O'Carroll, 2012). The studies assigned levels of risk to infrastructure based on a ratio of building height to flooding depth (Robichaud et al., 2011; Aubé and Kocyla, 2012). Maps were produced showing the intersection of flood extent and erosion zones with known infrastructure using aerial images, LiDAR surveys and available tidal and/or storm-surge data. The maps facilitated the participation of community members in identifying and agreeing to zoning-plan proposals with specific future time references (Robichaud et al., 2011; Aubé and Kocyla, 2012; Jolicoeur and O'Carroll, 2012). The five Mi'kmaq communities of the Bras d'Or Lakes recently completed a similar assessment of their coastal reservations as part of a first phase of assessing their vulnerability to climate change and identifying adaptation options (Daigle et al., 2015).

Another method for determining vulnerability involves integrated assessment of physical and social vulnerabilities. For example, an integrated team approach that combined physical-risk assessment (i.e., effects of sea-level–rise scenarios and/or storm surges on infrastructure) with social assets (i.e., beaches, parks and walking trails) and social values was used to examine avoidance, protection, accommodation and retreat options for specific locations in Yarmouth and Lunenburg, NS, and uses of community structures and spaces (Cochran et al., 2012; Johnston et al., 2012; Muise et al., 2012; Wollenburg et al., 2012). The work also tested different visualization techniques, ranging from static to interactive computer displays and a three-dimensional (3-D) physical model to depict flooding levels, in terms of their effectiveness in communicating risks. Although photo simulations were found to be the most engaging, a range of tools was considered to be beneficial (Maher et al., 2012). Coastal Impact Visualization Environment (CLIVE) is a geovisualization tool that allows users to combine data from numerous sources, including an extensive province-wide archive of aerial photographs, and the latest high-resolution digital elevation data (LIDAR) to develop analytical visualizations of coastal erosion regimes and scenarios of potential future sea-level rise (Hedley et al., submitted). The tool has been used to assess the vulnerability of coastal infrastructure on Prince Edward Island (Fenech et al., submitted).

Vulnerability assessments often emphasize the importance of incorporating the views of local residents, their experiences in dealing with past climate impacts and traditional knowledge. Community-level assessments can stimulate change, enhance community buy-in for solutions and provide a voice for those being affected, as well as record experiences of elders in the communities. Reports on the Prince Edward Island communities of Victoria, North Rustico, Mount Stewart and Souris incorporated key informant interviews with community members that included their personal historical photos and memories (Government of Prince Edward Island, 2011). In other areas, such as Sackville, NB, simple climate change adaptation tool kits have been developed for use by the local community (e.g., Marlin, 2013). The community of Cheticamp in Cape Breton, NS experienced a range of engagement activities from coastal monitoring to social media and the arts led by the Ecology Action Centre and academic and public partners (Brzeski, 2013).

5.5 IMPACTS

The effects of climate change are already being felt in the East Coast region and will continue to affect many aspects of life, ranging from health and well-being of human populations to the economy. A large number of the broad policy areas related to coastal planning and management, including economic development and public safety, will be impacted to greater or lesser degrees by climate change

(CBCL Limited, 2009). Although quantitative analysis of economic impacts is lacking for almost all sectors, ongoing research is beginning to address this gap (*see* Chapter 7, FAQ 11). This section briefly addresses three areas of impacts and associated vulnerabilities in the East Coast region: economy, public safety, and culture and heritage.

5.5.1 ECONOMY

The East Coast region's economy will experience both negative (e.g., infrastructure damage) and positive (e.g., longer tourism season) impacts as a result of climate change. Available research identifies agriculture, fisheries and tourism as being particularly sensitive to climate change, along with development and transportation of offshore oil and gas (Vasseur and Catto, 2008). A cross-sectoral concern is the potential impacts on infrastructure, including residential, commercial and institutional buildings.

While available literature focuses primarily on risks to economic sectors, one example of a potential opportunity arising from climate change is increased crop production and diversification of the agriculture industry as a result of longer growing seasons (Vassseur and Catto, 2008). This positive impact for agriculture could be partially or completely offset by negative impacts associated with insect outbreaks and other disturbances (Vasseur and Catto, 2008).

FISHERIES

The 598 small-craft harbours in the East Coast region reflect the importance of fisheries to this part of the country (Table 5). In 2010, East Coast fisheries accounted for 80% of the total volume of landings by weight and 86% of registered salt- and fresh-water fishing vessels in Canada (DFO, 2013a). In 2011, the commercial sea fishery in the East Coast region accounted for $1.82 billion in landed value and 710 530 metric tonnes (live weight) in commercial landings. The bulk of these landings were located in Nova Scotia, and Newfoundland and Labrador (Table 5).

The economic value of fisheries extends well beyond the landed value. In Nova Scotia, for example, commercial fisheries, post-catch processing and aquaculture cumulatively contributed more than $1.1 billion to the province's gross domestic product in 2006, with the majority of this being attributed to shellfish (Gardiner Pinfold Consulting Economists Ltd., 2009). The lobster fishery alone in the four Atlantic Provinces is valued at $550 million/year (Seiden et al., 2012).

Changing climate affects many aspects of fisheries ecology, including migration patterns and the timing of spawning and life-stage development, with significant economic implications. Wahle et al. (2013, p. 1571) termed 2012 "the year that drove climate change home" to the American lobster fishery. An ocean heat wave resulted in a glut of lobsters from the New England states before the close of the Canadian fishery, causing a dramatic drop in prices (Wahle et al., 2013). Changing migration patterns are resulting in mackerel (*Scomber scombrus*) arriving in the East Coast region later in the summer, such that their appearance no longer overlaps with the spring lobster and snow crab (*Chionoecetes opilio*) seasons. As mackerel is a staple bait species, the lack of bait is another stress for the local lobster-fishing industry. Bait purchased elsewhere is not cost effective for fishers, as bait prices increase with transportation and refrigeration costs (Brzeski, 2013).

In situations where capture-species populations become so depleted, whether as a result of changing climate, overfishing or other stressors, there are historical examples of fishers changing to focus on other species (Brzeski, 2013). However, regulatory regimes tend to limit this adaptation response (Charles, 2009; Miller et al., 2010), and Vasseur and Catto (2008) noted the need to make changes to licensing regulations to take into account the potential for species to migrate to new areas or disappear due to climate change.

Changing climate places additional stress on the fisheries sector as a whole. Fishers in the East Coast region already face maintenance and repair costs associated with aging infrastructure (e.g., wharves and processing plants), as well as conflicts over access, harbour management and competing land use. Existing infrastructure may become less usable with higher tides and storm surges, and/or accelerated erosion through increased wave action.

TABLE 5: Commercial fishery in the East Coast region, 2011 (DFO, 2013b, c).

Province	Small-craft harbours (fishing)	Live weight (metric tonnes)	Landed value ($)	Landed value ($/tonne)
Nova Scotia	163	258 677	731 992 000	2 829
New Brunswick	68	81 760	175 196 000	2 143
Prince Edward Island	46	30 789	111 106 000	3 609
Newfoundland and Labrador	264	283 923	641 978 000	2 261
Quebec	57	55 381	154 898 000	2 797

Breakwaters may be ineffective at certain points during the tide cycle or more susceptible to frequent surges. Fish plants located close to shore may be undermined or destabilized by erosion, or inefficient if wharves can no longer receive fish landings due to sea-level rise. A risk assessment by DFO (2012b) for the Atlantic basin identified damage to infrastructure (including harbours, breakwaters, wharves and navigation aids) as the greatest risk exposure to the department (Figure 14). The estimated impact of climate-related damages is very high and the likelihood of such damages is moderate to almost certain at the 10- to 50-year time scale (DFO, 2012b).

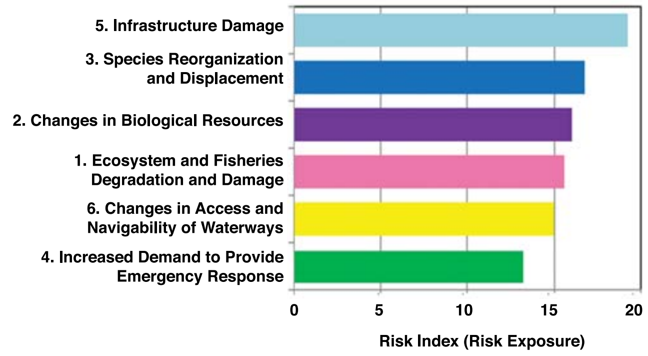

FIGURE 14: Index of climate change adaptation risks on the 50-year time scale for each of six risks identified by the Fisheries and Oceans Canada (DFO) with respect to their department operations. Risk evaluation was based on expert opinion of magnitude of impact (ranked from 0 to 5, where 5 is very high) and probability (also ranked from 0 to 5, where 5 is very high). The risk index is the product of the risk's impact and probability rankings. See DFO (2012b) for additional details on methodology.

AQUACULTURE

Climate change presents risks, and potentially some opportunities, to aquaculture, which is a rapidly growing part of the regional economy. In 2013, the East Coast region produced 49% of Canada's aquaculture by weight and 45.4% by total value ($427 million; Statistics Canada, 2014b). Newfoundland and Labrador, and Prince Edward Island are the top producers by weight, whereas Newfoundland and Labrador, and New Brunswick are the top producers by value (Table 6). Atlantic salmon (*Salmo salar*) is the most valuable species. Shellfish, particularly the blue mussel (*Mytilus edulis*), are the core of the aquaculture industry in Prince Edward Island, where the larvae are recruited from the wild and then cultured (Feindel et al., 2013).

Climate change will affect aquaculture via acidification, changes in seawater temperatures and circulation patterns, the frequency and severity of extreme events, and sea-level rise and associated ecological changes (Feindel et al., 2013; Shelton, 2014; Gurney-Smith, 2015; Reid et al., 2015). Possible operational impacts on aquaculture include infrastructure damage, loss of stock, positive and negative changes in production levels, and changing insurance costs (Table 7; Feindel et al., 2013).

Unlike wild species, cultured species cannot migrate to areas that are optimal for growth and survival. Although some environmental conditions can be moderated artificially for some species (e.g., land-based pens for Arctic char), others require *in situ* pens exposed to local oceanographic conditions of temperature, salinity, oxygen and acidity. Tolerance ranges differ greatly between species and for different conditions, and tolerance will also vary by life-cycle stage. Larvae are most sensitive to changes in optimal conditions. Some cultured species require the larvae to be harvested from the wild before being grown in compounds.

Impacts of ocean acidification are already a major issue globally for both wild and cultured populations of marine shellfish (Gurney-Smith, 2015). Negative responses have been reported in a large majority of North American studies on commercial species to date (Gazeau et al., 2013). These responses include shell deformation, low growth rates and high mortality of commercially important bivalves, such as the blue mussel (*Mytilus edulis*; Gazeau et al., 2010; Gazeau et al., 2013).

Research on Atlantic salmon has shown that an average increase in water temperature of 1°C over the production cycle will decrease time to market by approximately two months, thereby decreasing overall production costs (Reid et al., 2015). Although this suggests that small increases in average temperature could benefit aquaculture production, there are other stresses that must also be considered. For example, increased water temperatures may increase infection potential by reducing the time required for sea lice to complete their life cycle (Stien et al., 2005; Reid et al., 2015). Higher water temperatures may also lead to the introduction of pathogens to which the current genetic stocks in the East Coast region are unaccustomed (Reid and Jackson, 2014).

Selective breeding programs may be an adaptive solution (Waldbusser et al., 2010; Quinn et al., 2011), as could genomic research to select for genetic improvements within a species (Zhang et al., 2012; Millar, 2013). Otherwise, the geographic range of a species may be extended or narrowed depending on the individual species (Shackell et al., 2013). An obvious but operationally challenging option is to relocate the industry to cooler waters.

Both land-based and open-water aquaculture sites can be impacted by severe weather events, potentially rendering them inaccessible or facilitating escape of penned stock. For example, land-based pens within the Oak Bay Hatchery in New Brunswick, critical sites for egg production and brood-stock development and protection of Atlantic salmon, were flooded, and access restricted, in December 2010 (Reid and Jackson, 2014).

TABLE 6: Aquaculture production and value in 2013 in the East Coast region (Statistics Canada, 2014b). Source notes that the production and value of aquaculture include the amount and value produced on sites and exclude hatcheries or processing. Shellfish also includes some wild production. Detailed species-level data for finfish were not available for Newfoundland and Labrador or for Prince Edward Island. Abbreviation: N/A, not available for a specific reference period.

a) Production (tonnes)

Aquaculture Type	NL	PE	NS	NB	QC	All Canada
Finfish — Salmon	N/A	N/A	6 517	18 837	0	100 027
Finfish — Trout	N/A	N/A	203	0	1262	6 736
Finfish — Steelhead	N/A	N/A	0	0	0	682
Other finfish	N/A	N/A	60	0	1	696
Total finfish	22 196	N/A	6 780	18 837	1 263	130 337
Shellfish — Clams	0	0	358	0	0	2 834
Shellfish — Oysters	0	2 812	356	739	10	9 509
Shellfish — Mussels	4 354	22 894	1 051	41	448	29 080
Shellfish — Scallops	0	0	0	5	11	107
Other shellfish	0	0	203	5	22	230
Total shellfish	4 354	0	1 968	790	491	41 760
Total aquaculture	26 550	25 706	8 748	19 627	1 754	172 097

b) Value (thousands of dollars)

Aquaculture Type	NL	PE	NS	NB	QC	All Canada
Total finfish	181 833	3 229	43 386	117 334	10 854	870 346
Total shellfish	15 139	37 970	10 871	5 724	925	92 549
Total aquaculture	196 972	41 198	54 257	123 058	11 779	962 895

TABLE 7: Potential impacts of climate change on cultured species in the Atlantic Basin (*from* Feindel et al., 2013 [*as modified from* Handisyde et al., 2006] and Cochrane et al., 2009).

Drivers of change	Impacts on culture systems	Operational impacts
Changes in sea-surface temperature	▪ longer growing seasons ▪ changes in locations and ranges of suitable species ▪ reduced winter natural mortality ▪ enhanced growth and food-conversion rates ▪ decreased dissolved oxygen ▪ increased disease and parasites ▪ increased harmful algal blooms ▪ competition, parasitism and predation from altered local ecosystems, competitors and exotic species	▪ changes in infrastructure and operation costs ▪ increased fouling, pests, nuisance species and predators ▪ expanded geographic ranges for species ▪ changes in production levels
Changes in other oceanographic variables (wind velocity, currents and wave action)	▪ decreased flushing rates and food availability to shellfish ▪ changes in abundance of species used for food and fishmeal	▪ accumulation of wastes under nets ▪ increased operating costs
Sea-level rise	▪ loss of areas for aquaculture ▪ loss of areas providing physical protection	▪ infrastructure damage ▪ change in aquaculture zoning ▪ increased insurance costs
Increased storm activity	▪ larger waves ▪ higher storm surges ▪ salinity changes ▪ structural damage	▪ loss of stock ▪ facility and net-pen damage ▪ higher costs of designing new facilities and net pens ▪ increased insurance costs

TRANSPORTATION

Transportation by road, rail and ship, and the associated infrastructure, are critical elements of local and regional economies and social connectivity within and between communities. Most existing transportation infrastructure and operations were designed and constructed based on historical climate records and therefore might not be adequate to withstand future weather patterns and climate extremes (Auld and MacIver, 2007). Roads were commonly built to minimize the number of bridges required or limit the number of curves, with little consideration of coastal-erosion hazards (e.g., Drejza, 2010).

Climate change has the potential to substantially affect the effectiveness and lifespan of infrastructure in all of Canada, particularly infrastructure related to transportation and to marine and water management (Boyle et al., 2013). The exposure and vulnerability of these different types of infrastructure varies greatly. Adaptive measures can enhance climate resilience and lead to reduced costs over time. Local impacts associated with severe weather can be costly. For example, the New Brunswick Department of Transportation and Infrastructure reported repair estimates of approximately $750 000 throughout Charlotte County due to flooding on July 26, 2013 (Signer et al., 2014).

Road and rail freight in the East Coast region includes a wide range of imports and exports (Yevdokimov, 2008), with much of this traffic travelling between New Brunswick and Nova Scotia through the Chignecto Isthmus (Webster et al., 2012b). Disruption of this low-lying route stalls $50 million of trade per day (Webster et al., 2012b). Areas such as Prince Edward Island, Quebec's North Shore, Anticosti Island and the Îles de la Madeleine, and Newfoundland and Labrador are reliant on ferry or bridge connections that are very exposed to meteorological hazards. In Quebec, 60% of provincial roads in the estuary and Gulf of St. Lawrence areas are located less than 500 m from the coastline (Friesinger et al., 2013). Quebec's Department of Transportation is concerned about maintaining this essential service in light of changing coastal hazards, and has conducted several studies (Bernatchez et al., 2010). The road network is particularly important in the Îles de la Madeleine archipelago because it provides the only link between the islands and is vulnerable to being severed by major coastal erosion events (Section 6, Case Study 5).

Ports are another important element of the East Coast region's transportation network. There are 25 industrial sea ports that handle much of the import and export of bulk products and resources. Eight of those ports are managed by port authorities (Table 8). Changes in sea level, sea-ice conditions and the frequency of severe storms are likely to affect port operations in the region. Potential positive effects of climate change on commercial shipping include improved access by deeper draft vessels as water depths in harbours increase, and the reduction of sea ice in the Gulf of St. Lawrence that will increase the potential for more shipping to the Port of Montréal and the St Lawrence Seaway. Potential negative effects on shipping tend to be associated with damage to port infrastructure due to extreme weather events (Dillon Consulting and de Romilly & de Romilly Ltd., 2007).

TABLE 8: Tonnage handled by port authorities in the East Coast region (Association of Canadian Port Authorities, 2013). Port authorities account for 60% of cargo handled by Canadian ports (Statistics Canada, 2012).

Port Location	Tonnage handled (million tonnes)
Québec (QC)	29 (2011)
Sept-Îles (QC)	28 (2012)
Saint John (NB)	28 (2012)
Halifax (NS)	9.5 (2012)
Belledune (NB)	1.9 (2012)
St John's (NL)	1.4 (2012)
Saguenay (QC)	0.35 (2011)

Planning and co-ordination to address climate risks to transportation can be challenging due to the diversity of agencies involved. In Halifax, the second largest natural, deepwater, ice-free harbour in the world, for example, the federal government operates the home port and associated facilities of the Canadian Navy's Atlantic fleet and Air Command's Canadian Forces Base Shearwater, as well as bases for the Canadian Coast Guard and offices for a range of federal departments and agencies. The Halifax Port Authority, an agency of the Crown under Transport Canada, oversees operations of the Port of Halifax. Major industrial facilities, such as the Irving Shipbuilding Inc. shipyard, infrastructure of Canadian National Railway Company, the Imperial Oil Limited oil-storage facility and the Tuft's Cove Generating Station, occupy a significant proportion of the nearshore lands (Dillon Consulting and de Romilly & de Romilly Ltd., 2007).

TOURISM

International research indicates that climate change will affect a range of coastal recreational activities (e.g., beach visits, fishing and boating) both positively and negatively (e.g., Coombes and Jones, 2010). Direct and indirect tourism revenues are a significant component of the economy for many communities in the East Coast region. In New Brunswick, for example, visits to and within the province contributed almost $1 billion in tourism-related expenditures in 2008 (New Brunswick Department of Tourism and Parks, 2010), the vast majority of which were linked to the coast. In

Prince Edward Island, tourism is a critical driver of economic activity, employment and tax revenue, accounting for 6.9% of the island's GDP and $373 million in revenue in 2009 (Tourism Industry Association of Prince Edward Island, 2014). The economic contribution of the 500 000 tourists to Newfoundland and Labrador is estimated at approximately $450–470 million annually and also contributes to employment and small-business establishment (N. Catto, personal communication, 2015). In 2014, the Quebec Government unveiled an action plan (Stratégie de mise en valeur du Saint-Laurent touristique 2014-2020) to promote tourism within the St. Lawrence river, estuary and gulf regions, where tourism is already a key component of local economies (Tourisme Québec, 2014). For example, visitor traffic in the Îles de la Madeleine in the summer currently doubles the local population.

In examining approaches to adaptation, researchers have assessed the potential for collaboration between fishing and tourism industries, to improve overall economic stability within local areas. In Bonne Bay (NL), for example, the fishing and tourism sector are economically important to six small local communities. By enhancing the local experience for tourists through boat tours of the bay, improving local culinary services and offering historical interpretation of area, the economic future for both fishing and tourism sectors has improved (Lowitt, 2012). In Chéticamp, NS, a multidisciplinary research team developed a toolkit to help fisheries and tourism sectors adapt and remain competitive. The Chéticamp and Grand Étang harbour authorities are working to diversify harbour uses to enhance resilience, and the tourism association is promoting cultural tourism that provides indoor activities as an alternative to weather-dependent activities (Brzeski et al., 2013).

5.5.2 PUBLIC SAFETY

Changes to water quality, flooding and temperature extremes could impact the health and well-being of local residents. Flooding may adversely affect the ability of a geographically isolated group of residents to access emergency services, such as fire, medical and police (Muise et al., 2012; van Proosdij, 2013; Masson, 2014). In Windsor (NS), for example, a 1.2 m storm surge during an average high tide would flood road access to the hospital, including the access ramps to the major highway linking communities, whereas a 1.8 m surge would prevent emergency-response vehicles from leaving their station (van Proosdij, 2013). Even where hospitals and nursing homes may not be directly at risk from flooding, infrastructure and assets in support of daily living, such as grocery stores and pharmacies, as well as infrastructure that supports recreational, social and spiritual needs, can be directly or indirectly affected (Rapaport et al., 2013).

Costs associated with climate hazards can directly impact individual well-being. Homeowners in Canada generally cannot purchase insurance coverage for damages caused by overland flooding, including flooding from rivers, storm surges, tides and sea-level rise. In addition, erosion associated with overland flooding, including coastal erosion, is not covered under typical homeowner policies (Sandink, 2011). Behavioural changes, such as avoiding building or living in areas at high risk from such hazards, and heeding evacuation notices, would reduce the direct impact on individuals.

Major financial costs tend to be associated with extreme weather events. Flooding has been the most common type of disaster in the East Coast region, followed by hurricanes and winter storms (Public Safety Canada, 2014). Between 2003 and 2011, damage caused by three hurricanes and one major winter storm in the region resulted in insured losses ranging from $51 million to $132 million (Kovacs and Thistlethwaite, 2014). Catastrophic losses due to rising water and weather events, including more frequent rain-on-snow flooding and more frequent winter thaws that are anticipated to affect ice-jam flooding and river/estuarine drainage, will continue to increase with projected changes to climate in the East Coast region. Combined with current development pressures and practices, this may set the course for higher damages to built infrastructure and services (e.g., PIEVC, 2008).

5.5.3 CULTURE AND HERITAGE

At a global scale, the vulnerability of coastal archeological resources is well acknowledged (e.g., English Heritage, 2008; Blankholm, 2009; Marzeion and Levermann, 2014). Canada's East Coast region has a wealth of cultural and heritage resources, such as parks (national, provincial, municipal), UNESCO sites, museums, heritage architecture, undeveloped archeological sites, abandoned cemeteries, and sites of important aesthetic and spiritual value. Climate change can affect culture and heritage directly through physical damage to sites, structures and landscapes, or indirectly through impacts to economic resources that could undermine efforts to maintain and preserve cultural heritage. The prospect of loss or damage to historical and archeological resources in nearshore areas is often more significant to society than damage to contemporary structures that can be rebuilt.

Coastal erosion plays both destructive and discovery roles with respect to cultural heritage. Within the East Coast region, there are coastal and watercourse sites from all chronological periods of history (Paleo-Indian, Archaic, Woodland Ceramic, Proto-Historic/Contact and Historic). Examples include Tyron, PE; Meadford, NS; Sainte-Anne-des-Monts and Marsoui, QC; Port-au-Choix, NL; and Amherst Shore, NS (Chapdelaine, 1996; Bell and Renouf, 2003; Kirstmanson, 2011). For sites such as Pointe-aux-Vieux, PE, located on an actively eroding shoreline, the constant threat from climate impacts raises fundamental issues about the identification, protection and management of archeological sites. Although it would generally be preferable to leave portions of the archeological deposits intact for future generations to interpret, many sites, or a substantial portions of them, will eventually be lost to erosion by increments or by a catastrophic event (Case Study 4).

CASE STUDY 4

COASTAL ARCHEOLOGICAL RESOURCES AT RISK

Although coastal archeological sites have been inundated by rising water levels in many parts of Atlantic Canada for millennia (Lacroix et al., 2014), recent loss or damage by storm surges and erosion has raised the alarm for heritage managers to potential future threats (e.g., Duggan, 2011; Finck, 2011; McLean 2011). One study estimated that one-fifth of all coastal archeological sites in three regions of Newfoundland are highly vulnerable to sea-level rise during the next 15–20 years, including national historical and world heritage sites (Westley et al., 2011). A similar study is underway for Prince Edward Island (Kirstmanson, personal communication, 2014). At a more local scale, Parks Canada classified 16 of 18 areas of the Fortress of Louisbourg National Historic Site as vulnerable to impacts from sea-level rise within the next century (Duggan, 2011). The Coastal Archaeological Resources Risk Assessment (CARRA) project, based at Memorial University of Newfoundland, aims to refine and expand on the vulnerability-assessment approach for heritage managers so they can readily identify at-risk sites, prioritize those for immediate action and learn through a community of practice how best to respond (Pollard-Belsheim et al., 2014).

For the most part, the response of the heritage management community to the impacts of sea-level rise and coastal change has been reactive. Regular monitoring for erosion of coastal archeological sites is rare and typically limited to protected areas (e.g., national parks) or sites near communities. As a result, loss of or damage to many sites goes undetected. Response measures range from rescue excavation of rapidly eroding or submerging sites to protection of sites through armouring or hardening of eroding shorelines (Figure 15). Protective measures are mostly informal and have had mixed results. In Bonavista Bay, NL, for example, a gabion rock wall has effectively protected the Inspector Island site for almost 30 years, whereas wooden breakwaters at the Beaches site failed within five years of installation (Figure 16; Pollard-Belsheim et al., 2014). Proactive adaptation requires the prioritization of at-risk sites, a process that should integrate cultural values, socio-economic factors and public input (e.g., Duggan, 2011) with an assessment of physical threats and the adoption of site action plans that enable implementation of excavation, protection or abandonment.

FIGURE 15: Malagawatch Cemetery, NS, where buried human remains eroded into the sea following several storm events. Initial protection of the site involved the use of stone armouring (as seen below the cross). Subsequent storms and erosion led to temporary protection of burials using anchored hay bales and a permeable membrane (centre of photo). Planning for more permanent protection is ongoing. *Photo courtesy of Heather MacLeod-Leslie.*

FIGURE 16: Two different construction methods used to protect archeological sites in Bonavista Bay, NL: **a)** the stone gabion wall constructed at Inspector Island (Pastore, 1987) has successfully protected the site for three decades; **b)** wooden breakwaters have consistently failed at the Beaches site. *Photo b) courtesy of Anita Johnson-Henke.*

Coastal erosion can also expose previously unknown archeological and paleontological resources. For example, coastal erosion at the Joggins Fossil Cliffs, NS, a UNESCO World Heritage Site, has led to the recent discovery of fossilized footprints from the smallest known Tetrapod (*Batrachichnus salamandroides*) from the Carboniferous Period (approximately 360–299 million years ago; Stimson et al., 2012). New fossils are exposed with every storm and the challenge becomes accessing the new resources before they are washed away with the tide.

As the impacts of climate change accelerate, it will become increasingly important to determine which heritage sites are most at risk and which have the most value culturally and economically (Westley et al., 2011). For example, of the archeological sites at L'Anse-aux-Meadows, NL, 60% are considered to be of high vulnerability (mostly in Sacred Bay), 16% moderate and 24% low (Westley et al., 2011). This type of assessment can help concentrate preservation/recovery efforts or to understand the realities of abandonment.

Climate change will directly affect the assets of many parks in the East Coast region (e.g., Vasseur and Tremblay, 2014), and management plans are beginning to reflect these risks. Prince Edward Island National Park, for example, faced with a 1 m/year recession rate and with storms capable of eroding 10 m in a single event, has accepted planned retreat as an appropriate approach to adaptation, abandoning campgrounds and relocating the main coastal road landward in an effort to maintain and enhance natural coastal processes.

Most First Nations communities in the East Coast region have traditional ties to the coast. For example, Malpeque Bay (PE) has been crucial to the Mi'kmaq for food harvesting, transportation and recreation, among other uses, during a long history that spans thousands of years (Charles, 2012). Many First Nations continue to occupy areas vulnerable to climate change and to rely on coastal natural resources. The community centre of the Mi'kmaq Confederacy of Prince Edward Island on Lennox Island, for example, occupies a highly erodible island joined to the mainland by a short causeway and bridge. Concerns related to climate change include potential saltwater intrusion and threats to Mi'kmaq archeological sites in the area. These concerns are being addressed in an ongoing study led by the Confederacy: *Adapting the PEI First Nations' Coastal Residences, Infrastructure and Heritage to a Changing Climate on Prince Edward Island* (Mi'kmaq Confederacy of PEI, 2014).

6 ADAPTING TO CLIMATE CHANGE

Adapting to climate change in the East Coast region brings direct economic benefits (*see* Chapter 3) and is important for preserving vulnerable ecosystems and landscapes, and for securing sustainable regional development. In implementing adaptation, attention must be given to the multiple biophysical and socio-economic factors that together produce the complexity inherent to coasts and coastal communities, including climate, geomorphology, coastal dynamics, and environmental, legal and regulatory processes. Adaptation is a process that includes assessing risks and vulnerability at various time scales, identifying options to reduce or eliminate these risks, and assessing these options in terms of their impact on the neighborhood, on coastal ecosystems and on the economy. Often, adaptation is not an individual process but rather involves multiple levels of decision makers, including community members. Examples of maladaptation, actions that lead to increased risk of adverse climate impacts (IPCC, 2014), are also common in the region. Many factors have contributed to this maladaptation, including a frequently limited understanding of coastal dynamics, conflicts of interest and lack of knowledge about alternative options (Friesinger and Bernatchez, 2010; Novaczek et al., 2011; Graham et al., 2013; Niven and Bardsley, 2013; Cooper and Pile, 2014).

The following sections address many of the complexities of the natural and human (institutional) environment as they relate to the identification, assessment and implementation of adaptation measures in the East Coast region. Such analysis commonly forms the foundation for selecting specific adaptation options. An overview of the broad categories of adapting to coastal erosion, sea-level rise and coastal flooding, with examples from the East Coast region, precedes a summary that focuses on future directions.

6.1 THE CHALLENGE OF A CHANGING ENVIRONMENT

The preceding sections have highlighted many of the biophysical and socio-economic factors that influence changes in coastal environments (*see also* Chapters 2 and 3). Understanding the dynamics of such environments is fundamental to the development of adaptation measures (Spalding et al., 2014). With respect to changes in the coastline, the projected acceleration of sea-level rise, decreases in sea-ice and ice-foot cover, and the potential increase in effective storms suggest that historical erosion rates almost certainly underestimate future coastal retreat. In a study of three areas in the East Coast region (Îles de la Madeleine, Percé and Sept-Îles QC), Bernatchez et al. (2008a) developed three scenarios for future coastline position by the year 2050 (Case Study 5). Modelling of these scenarios contributed to the delineation of three setback zones of varying vulnerabilities to coastal erosion. A similar project undertaken along the north shore of Prince Edward Island incorporated changes in shoreline configuration due to exposure and wave stress at the coast (MacDonald, 2014).

CASE STUDY 5

PLANNING FOR COASTLINE MOBILITY IN THE ÎLES DE LA MADELEINE

Located in the centre of the Gulf of St. Lawrence, the Îles de la Madeleine is an archipelago of 10 islands (total area about 190 km^2) with a population of approximately 12 600. The living area of the archipelago is restricted, with the maximum width of rocky outcrops not exceeding 10 km and their central part often being high and steep (Figure 17). Tourism is a key component of the local economy (Section 5.5.1). The Îles de la Madeleine are vulnerable to coastal hazards, and the archipelago is particularly sensitive to erosion. Coastal infrastructure on the Îles de la Madeleine is threatened by shoreline retreat at several sites, including the main road network of the archipelago and the sewage purification ponds of the main community. In its master plan, the Municipality of Les Îles-de-la-Madeleine identified 23 areas where erosion is an issue and where action is deemed necessary (Municipality of Les Îles-de-la-Madeleine, 2010).

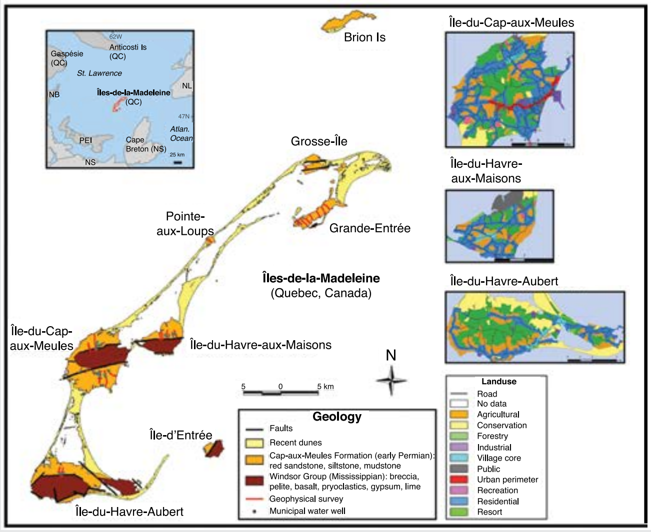

FIGURE 17: Location, geology and land use on the Îles de la Madeleine (Rémillard et al., 2012).

The archipelago is more vulnerable to relative sea-level rise than any other area in Quebec. This relates, in part, to the fact that it is a microtidal environment, with only about 1 m difference in height between low tide and high tide. With sea level around the Îles de la Madeleine in the year 2100 projected to be 50–83 cm higher than at present, and as much as 150 cm higher in the scenario involving partial collapse of the West Antarctic Ice Sheet (based on curves for Charlottetown presented in Figure 5 and Appendix A; James et al., 2014; *see also* Chapter 2), the current position of the high tide could roughly correspond to the position of the low tide in 2100. This shifting of the intertidal zone will change the position of the coastline and affect habitats, coastal ecosystems, coastal dynamics and erosion rates.

To assess the potential impacts of future changes in climate, Bernatchez et al. (2008a) proposed three possible positions of the coastline for the year 2050 (Table 9). The mapping of these scenarios along the coasts of the archipelago enabled stakeholders, scientists and members of working groups to identify adaptation options for targeted priority sites. Options considered included sand nourishment; a combination of sand nourishment, groynes and eolian sand traps where the main road is threatened; and rip-rap defence structure (armour stone) where erosion is threatening the community core (Figure 18; Savard et al., 2008).

TABLE 9: Erosion scenarios developed for communities in the Gulf of St. Lawrence and used to map the evolution of the coastline to the year 2050 (*translated from* Savard et al., 2008).

Scenarios for 2050	Description
S1: average coastline displacement rate between 1931 and 2006	Assumes that the effect of climate change will not modify the average rates of coastline retreat to 2050
S2: average erosion rates measured for a range of 10–15 years where erosion was most intense during the period 1931–2006	Considers probable accelerated coastal erosion due to climate change
S3: average values of higher-than-average rates of retreat for a range of 10–15 years where erosion was most intense during the period 1931–2006	Considers as likely a high acceleration of erosion due to climate change and aggravating anthropogenic factors

Their analysis concluded that, by 2050, the rocky cliffs of the Îles de la Madeleine could erode by about 38 m (–0.9 m/year) and sandy coasts could retreat by about 80 m (–1.9 m/year) (Bernatchez et al., 2008a; Savard et al., 2008). Under this scenario, many sites in the archipelago will be at high risk in the near future, including portions of the main road where only a single foredune ridge separates it from the westerly exposed beach and some community infrastructure and tourist sites. The overall picture demonstrates that coastal erosion exacerbated by climate change is a chronic and serious problem in the Îles de la Madeleine. Nevertheless, based on an understanding of coastal dynamics and acceptance of inevitable changes, the decision was made to leave 95% of the archipelago's territory unprotected from natural processes such as erosion and flooding. This approach preserves the natural beauty of the archipelago, which is a primary draw for tourists, and the islands are sufficiently high and large to endure shoreline retreat for many centuries. Only a few town centres with critical infrastructure are protected with a mix of hard and soft protection methods (Section 6.3.4).

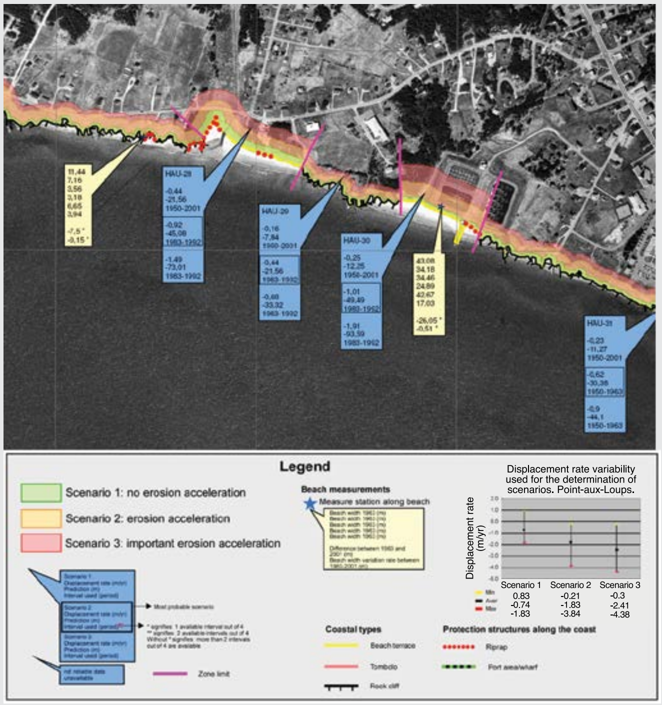

FIGURE 18: Example of digital-mapping scenarios and setbacks S1, S2 and S3 in Cap-aux-Meules, Îles de la Madeleine (*adapted from* Savard et al., 2008).

The study by Bernatchez et al. (2008a) was a first attempt to address how the local coast will evolve in the 21st century, knowing that the past does not represent an analogue for the future. Continued research and production of rigorous scientific documentation on the response of coastal systems to projected conditions will help better support decision making.

Risk management, analysis and the implementation of adaptation solutions to address changes in the coast often benefit from an approach based on uniform coastal units, usually littoral cells (*see* Chapter 2; Schéma Directeur d'Aménagement et de Gestion des Eaux du bassin Rhône-Méditerranée-Corse, 2005; de la Vega-Leinert and Nicholls, 2008; Dawson et al., 2009). Interventions made in one area of a littoral cell will impact the rest of the cell (MacDonald, 2014). Failure to take account of this important aspect of coastal dynamics can lead to maladaptation.

6.2 INSTITUTIONAL FACTORS AFFECTING ADAPTATION

The legal and institutional frameworks defining land policy in coastal regions can be key in facilitating adaptation or, in some situations, can serve as barriers to adaptation (e.g., Doiron, 2012). Policies may include defining areas with protection status for biodiversity, municipal zoning and development strategies and plans. The majority of laws, regulations and codes of practices in place today do not include consideration of changing climate and would benefit from review with a climate change lens. Indeed, much recent construction in the East Coast region has occurred in areas of high flooding risk yet is compliant with existing land-planning regulation and legislation. There are, however, important exceptions to this general characterization that reflect recent advances in adaptation planning (Case Study 6).

CASE STUDY 6

DEVELOPED WATERFRONT AND VERTICAL ELEVATION LIMITS IN HALIFAX REGIONAL MUNICIPALITY

Halifax Regional Municipality (HRM) is the capital of Nova Scotia and Atlantic Canada's largest city. The municipality covers more than 5500 km^2 and has a population of more than 414 000 (Statistics Canada, 2014a). Halifax Harbour, at the heart of HRM, is a major seaport with significant industrial, military and municipal infrastructure, including culturally important assets. In response to extreme weather events, such as Hurricane Juan, a Category 2 hurricane that caused an estimated $200 million in damage in Nova Scotia and Prince Edward Island in 2003, and a major winter storm in 2004, HRM began to actively implement climate change adaptation measures (Charles and Wells, 2010). In 2006, the HRM Council adopted the Regional Municipal Planning Strategy, which explicitly included policies to address climate change impacts. The strategy highlighted that scientific information is the foundation for adaptation-planning processes, particularly as it relates to sea-level change, storm surges and coastal vulnerability, to inform development of an area-specific land-use plan for Halifax Harbour (HRM Department of Energy and Environment, 2013).

In partnership with Natural Resources Canada, the HRM Department of Energy and Environment evaluated future sea-level rise and flooding risk around Halifax Harbour during the next 100 years for three scenarios that considered present and future sea-level rise, vertical land motion, statistics of extreme water levels (combined tide and surge), wave run-up and harbour seiche (Forbes et al., 2009). Mapping of future flood-hazard zones (Figure 19) utilized a high-resolution digital elevation model based on LiDAR data.

The scenarios of global sea-level rise used by Forbes et al. (2009) were based on projections of the IPCC Fourth Assessment Report (IPCC, 2007) and subsequent scientific literature. Although those scenarios are superseded by the projections presented in this report (Section 3.1 and *see* Chapter 2), both sets of scenarios cover a similar range. The 57 cm sea-level rise presented in Figure 19 compares with updated projections of relative sea-level rise for 2010–2100 at Halifax of 60.6 cm for RCP4.5 (median) and 84.7 cm for RCP8.5 (median; James et al., 2014, 2015). It is therefore quite a conservative scenario.

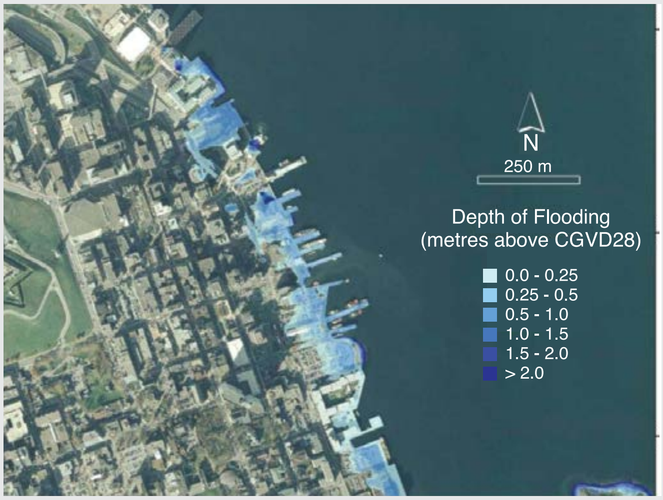

FIGURE 19: Flooding extent and depth (still-water) for a 57 cm sea-level rise with a once-in-50-years extreme-water-level event in downtown Halifax, derived using a light detection and ranging (LiDAR) digital elevation model displayed over a digital airphoto image (Forbes et al., 2009).

Based on available analysis, and following a precautionary approach, the Municipal Planning Strategy and Land Use By-Law for the downtown Halifax waterfront area prescribes any ground-floor elevation development to be a minimum 2.5 m above the ordinary high-water mark. Provisions were made for this figure to be adjusted based on ongoing monitoring and analysis of sea-level rise. This is an example of an adaptation measure being incrementally adjusted as new information becomes available. In the interim, HRM staff have used development agreements (i.e., bilateral contracts between the municipality and the landowner) for a number of waterfront parcels to encourage safe development while a formal adaptation plan is being completed (Charles and Wells, 2010).

Building upon the findings of Forbes et al. (2009), Xu and Perrie (2012) modelled extreme wave run-up within Halifax Harbour. Although development proponents are not presently required to demonstrate that extreme waves and wave run-up effects have been incorporated into their project design and engineering, information from this research study could be considered in amendments to land-use by-laws. For instance, development proponents could be required to conduct site-specific wave studies and demonstrate that appropriate adaptive responses have been incorporated into the overall design (HRM Department of Energy and Environment, 2013).

The availability of a high-resolution digital elevation model for a complex coastal urban landscape such as HRM has provided significant opportunities for community engagement and visualization of hazards. It assists in delineating zones of vulnerability and prioritization of sites for protection, relocation and enforcement of setbacks. Setbacks can be updated as new data and information become available.

Vertical and horizontal setbacks are useful mechanisms to promote adaptation, and their utility is not limited to large municipalities. For example, the Municipal Council of Beaubassin-Est, NB passed an updated zoning by-law in March 2011 to enhance protection of new construction in its coastal zone (Eyzaguirre and Warren, 2014). The by-law requires 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 (Doiron, 2012). All previous zoning conditions still apply. In Prince Edward Island, coastal setbacks are legislated based on measured erosion rates (1958, 2000 and 2010), supplemented with field observations. Wetlands and streams near cliffs must be protected by a buffer of 15 m or 60 times the erosion rate of that section, whatever is greatest (Arlington Group et al., 2013; Weissenberger and Chouinard, 2015). In Quebec, construction is prohibited below the high-tide line as part of a policy on the protection of shores, littoral zones and floodplains. Although construction in the flood plain is permitted, no living space, door or window may be located below the level of a once-in-100-years flood (Weissenberger and Chouinard, 2015).

Opportunities exist for the integration (mainstreaming) of coastal and/or climate-change adaptation elements into existing legislation, policies and practices, including building codes and codes of practice for engineers, planners and landscape architects. In most jurisdictions, municipalities and other land-management organizations identify areas at risk for erosion, landslide and flooding. Municipalities in Quebec, Nova Scotia, and Newfoundland and Labrador are required to prepare public-safety plans that are integrated in the municipality's land-policy and land-management plan. Such plans can be important in driving adaptation if they are developed with an understanding of how climate change is impacting coastal hazards.

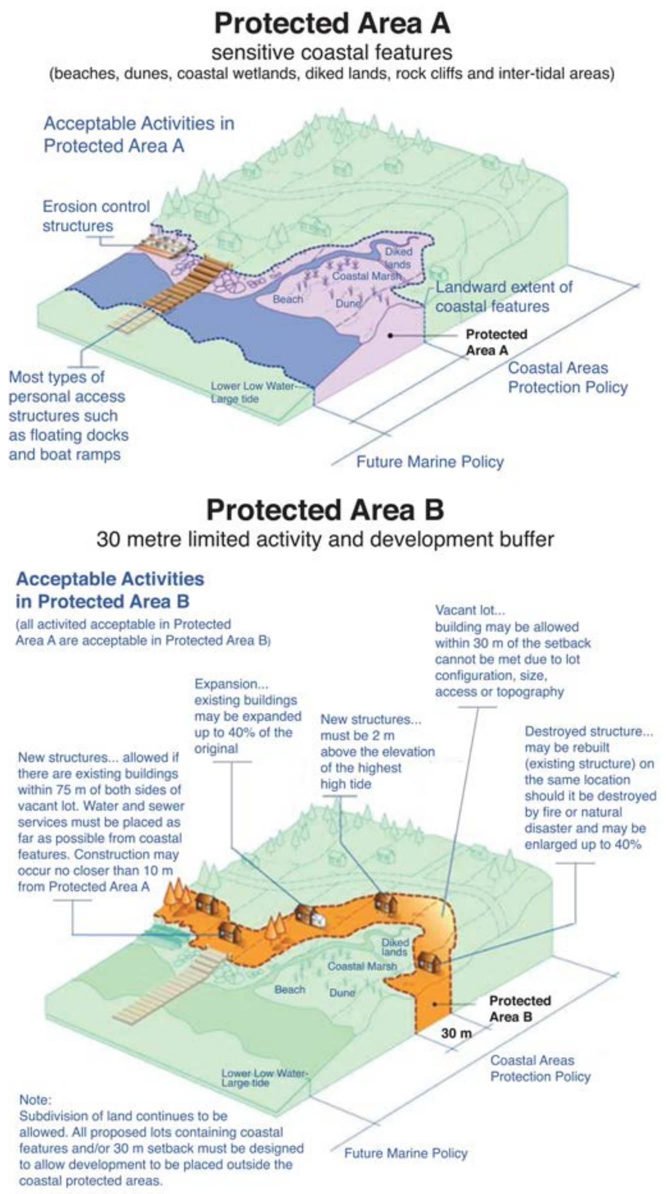

FIGURE 20: Zones A and B of the New Brunswick *Coastal Areas Protection Policy* (New Brunswick Department of Environment and Local Government, 2002).

Changing legal and regulatory frameworks tends to be a slow process. One of the earliest examples of planning for coastal change is the New Brunswick *Coastal Areas Protection Policy*, developed in 2002 in recognition of the stresses that threaten public safety, infrastructure, agricultural lands and the biodiversity of plant and wildlife within the region. This policy identifies sensitive coastal features, allowing these to continue to function naturally and maintain their buffering capacity, then identifies a 30 m limited-activity and -development buffer that begins at the farthest landward extent of the dynamic coastal zone (Figure 20; New Brunswick Department of Environment and Local Government, 2002). Although proactive and innovative at the time it was introduced, challenges in implementation have been ongoing and, as of 2013, it still did not have the force of law (Weissenberger and Chouinard, 2015). Interim measures are sometimes employed while broader regulatory changes are being considered. In Quebec, an interim regulation has been implemented to prohibit construction in areas of coastal risk on the North Shore from Québec to Blanc-Sablon (Case Study 7). The regulation is subject to review and adjustment as new scientific knowledge becomes available.

CASE STUDY 7

ADDRESSING COASTAL EROSION IN SEPT-ÎLES, QC

The Municipality of Sept-Îles, QC has been dealing with erosion and coastal change, related to natural processes and human influences, for decades (Bernatchez and Dubois, 2004; Bernatchez and Fraser, 2012). In the late 1990s, the municipality requested a detailed study on the issue of erosion and a plan for coastal management based on integrated solutions (Dubois et al., 2005). The resulting four-year (2000–2004) scientific assessment concluded that coastal erosion had accelerated in recent decades, that human interventions at the coast were amplifying natural rates of erosion and that climate change could accelerate erosion in the future (Dubois et al., 2005). A follow-up study (2005–2008), led by the Ouranos consortium and the Quebec Department of Public Safety, assessed the vulnerability of coastal communities along the province's eastern shores, including the Municipality of Sept-Îles (Figure 21). The study used a participatory approach, taking into account the views of stakeholders and transferring climate science to decision makers to facilitate an integrated coastal-management approach and to identify adaptation options (Savard and Bourque, 2008, 2010; Savard et al., 2009). Local stakeholder representatives were invited to participate in a series of day-long workshops to identify adaptation solutions. The approach required that decision be achieved by consensus (Savard et al., 2008; Savard and Bourque, 2010).

The study highlighted that changes in storm frequency lead to significant retreat of sandy coasts; that increased winter thaws intensify freeze-thaw processes on clay cliffs; that decreases in seasonal sea-ice coverage in the Gulf of St. Lawrence increase the development of energetic winter waves that reach the coast; and that all of these climate-related factors are acting in the context of a rising sea level. The study was a catalyst for many events, meetings and consultations among community representatives, municipal and government policy makers, and members of the study's scientific committee.

The scientific documentation and the consultation with community stakeholders arising from the study were crucial in the adoption of control measures in the Sept-Rivières Regional County Municipality, measures with which the City of Sept-Îles must comply (Municipalité régionale de comté de Sept-Rivières, 2005; Natural Resources Canada, 2015). These include:

- adoption of a safety setback margin calculated over a period of 50 or 100 years, depending upon whether it is private or public land;
- development of future erosion scenarios (2050) to identify appropriate adaptation options;
- a ban on the installation of traditional protection structures (rip-rap, concrete walls, wooden walls, groynes and revetments); and
- a ban on any increase of habitable surface area for buildings in designated no-construction zones.

This regulation is now fully enacted across the Province of Quebec. Representatives of the provincial government, regional county municipality and the City of Sept-Îles are working to establish a master plan for coastal intervention, in order to deal with erosion and coastal management problems over the short, medium and long term (Natural Resources Canada, 2015). For example, the municipality decided to move part of the coastal population living on a sand cliff located along the gulf shores of the Sainte-Marguerite River estuary.

A final component of the study was a cost-benefit analysis over a 25-year period (2008–2032) of the adaptation options identified through the consultation process (Tecsult

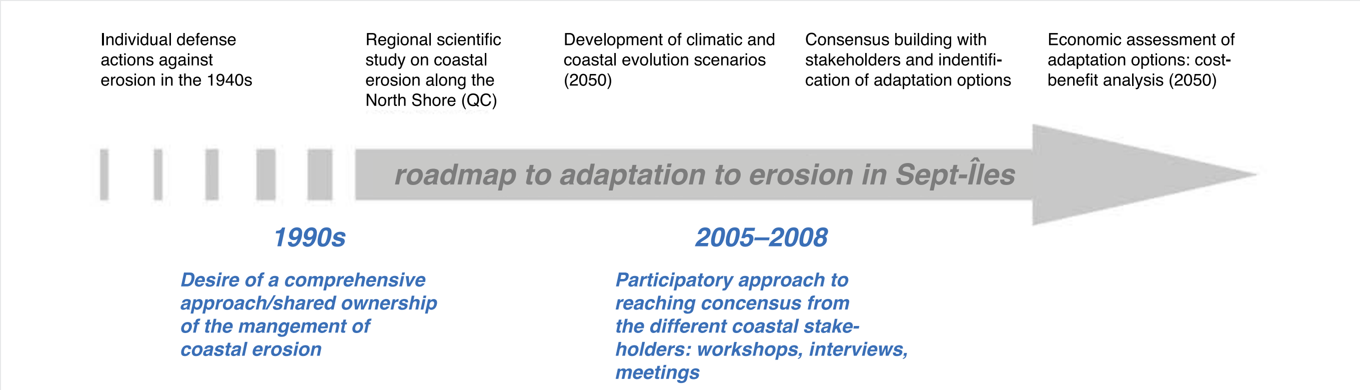

FIGURE 21: Main actions and interventions in the process leading to adaptation to erosion in Sept-Îles, QC.

Inc., 2008). The options studied, which varied from location to location, were sand nourishment, linear rock armourment, a combination of groynes and sand nourishment, revegetation, and planned relocation. The analysis showed that the optimal adaptation scenarios were those favouring sand nourishment or planned relocation. Under the Major Natural Hazards Prevention Guidelines (Cadre de prévention des principaux risques naturels), the Quebec Department of Public Safety had funds specifically earmarked for adaptation to coastal erosion. The Regional Municipality of Sept-Îles was approved for funding under this program for an $8 million sand-nourishment project, with the municipality required to provide 25% of the funding (approximately $2 million). A tax levy was proposed to raise the funds, but the local government had difficulty obtaining public support as the levy would have been applied to all residents, whereas only the ocean-front property owners were perceived to benefit from the project (Arlington Group et al., 2013).

Availability of financing is another example of an administrative control on adaptation. It is often easier to obtain financing for hard engineering projects, such as seawalls and rip-rap, than for more flexible options, such as beach nourishment and dune or marsh restorations that require ongoing financing over a long-term period (even though the cost-benefit ratio can be better than for hard protection methods; Spalding et al., 2014). Some financing may be available through avenues such as habitat compensation projects for loss of aquatic habitat due to infrastructure construction, with the primary goal of such coastal wetland restoration projects being habitat creation (Bowron et al., 2012). Lack of public support can also be a barrier to funding of implementation measures (Case Study 7).

6.3 COASTAL ADAPTATION OPTIONS

Although specific adaptation measures are diverse, adaptation options in coastal areas can be grouped into four broad categories: no active intervention, avoidance/retreat, accommodation, protection, or a combination of these approaches (*see* Chapter 3; Chouinard et al., 2008; Vasseur and Catto, 2008; Pilkey and Young, 2009; Linham and Nicholls, 2010; Nicholls, 2011; Burkett and Davidson, 2012; Arlington Group et al., 2013; Macintosh, 2013; Niven and Bardsley, 2013). Coastal settings located between urban areas and relatively natural areas can be particularly challenging with respect to determining appropriate adaptation measures. There is a large array of feasible adaptation options where the coast is occupied by low-density settlements, such as a line of cottages, houses or suburban commercial assets. Rapid linear urban expansion, often referred to as ribbon development, has occurred along many stretches of the coast in this region during the past few decades, resulting in significant economic assets being at risk from coastal hazards and exacerbating coastal squeeze (Section 4.8).

6.3.1 NO ACTIVE INTERVENTION

No active intervention can be a legitimate adaptation response when, based on a thorough understanding of the risks involved, decision makers choose to take no action at this time. No active intervention may be appropriate when there is no significant risk, when little can practically be done to avoid or reduce the impacts of coastal hazards, or when action taken now is an inappropriate allocation of resources against the potential of a future threat. As described in Case Study 5, a rigorous adaptation planning process for the Îles de la Madeleine led to the decision to make no active intervention with respect to 95% of the archipelago's territory.

6.3.2 AVOIDANCE AND RETREAT

The option of avoidance and retreat involves identifying risk areas and defining where development will be prohibited, while enabling existing housing and infrastructure at risk to be relocated to safer areas. These options are most commonly suggested for the preservation of natural landscapes and coastal ecosystems, and applied in areas with few coastal-infrastructure assets. For example, Prince Edward Island National Park acquired 12.5 km^2 of land in the mid-1970s along the landward portion of the park boundaries to compensate for the land losses along the shoreline. This land is now being managed as a buffer to gradually relocate coastal infrastructure as the shoreline moves landward (Parks Canada, 2007). In urban centres, where major assets are concentrated, retreat options are challenging because there is no room for accommodation and the cost of retreat, both economically and culturally, would be enormous.

Even outside urban centres, avoidance and retreat may not be generally preferred strategies on the basis of short-term economics. Coastal land is often a significant source of revenue for municipalities and leaving this land unoccupied by direct revenue-generating activity is often seen as a negative economic factor. Another drawback of avoidance is that facilities and people are commonly already present in the high-risk area (Lieske and Borneman, 2012; van Proosdij et al., 2014). Public consultation and information are particularly important in achieving successful adaptation through avoidance and retreat (Savard and Bourque, 2010; Drejza et al., 2011).

Avoidance and retreat in the East Coast region also includes managed realignment in diked areas, such as in the upper Bay of Fundy. There has been increasing interest in this concept during the last few years with the recognition that the cost of maintaining the existing system of dikes in Nova Scotia and New Brunswick is not sustainable (Lieske and Borneman, 2012; van Proosdij and Page, 2012; Wilson et al., 2012; van Proosdij, 2013). Although most salt-marsh restoration projects in the bay have been conducted as habitat compensation (van Proosdij et al., 2010; Bowron et al., 2012), there is growing interest in maximizing the adaptation potential of such projects while enhancing ecosystem services (van Proosdij et al., 2014). Close monitoring of selected salt-marsh restoration projects has shown rapid recolonization of vegetation, and therefore enhanced potential for wave-energy dissipation, after tidal flow is restored. The pace of this recovery, however, is not spatially uniform (Millard et al., 2013; van Proosdij et al., 2014).

6.3.3 ACCOMMODATION

Accommodation responses seek to lower the risks of climate hazards without fundamentally changing land usage by allowing for occasional short-term impacts (e.g., impacts from storm events or seasonal flooding). Accommodation is an appropriate response when the practicality of protecting coastal assets is outweighed by the economic, environmental or social costs, and/or when the effectiveness of protection measures would be limited to a relatively short period of time (*see* Chapter 3).

In the East Coast region, there are a few examples of structures planned to accommodate sea-level rise or storm surge, such as homes or other buildings constructed on stilts, or modular buildings designed to be easily moved (Vasseur and Catto, 2008; Doiron, 2012). Storm-water management that decreases runoff (e.g., vegetated swales and green space), increases conveyance (e.g., dredging channels and engineering drainage design with culverts that are appropriately sized for climate change) and increases storage (e.g., storm-water retention ponds and rain gardens) can be a very important accommodation option in addressing flooding. For example, evaluation of the 2003 storm-water management plan for Stratford, PE determined that numerous culverts within the town would not be able to accommodate projected changes in rainfall intensity associated with climate change, and that there was a need for increasing drainage capacity in order to accommodate larger runoff volumes. Increasing culvert size may not be beneficial, as larger and stronger drainage flows could lead to increased erosion. Instead, a combination of pipe upgrades, additional storage within tributary watersheds, abandonment and appropriate flood-proofing and hazard-warning systems in selected areas has been proposed to decrease damage and the threat to residents (CBCL Limited, 2012).

Accommodation includes accepting temporary inundation of noncritical infrastructure (e.g., flooding of secondary roads where alternative access routes exist for fire or other critical services). Cost-benefit studies can be used to assess the cost of modifying or displacing the road versus accepting occasional closure or repairs for several decades. Improved predictability of extreme events can enable actions such as evacuation of persons at risk and temporary protection of buildings and properties to happen in advance of a major storm.

6.3.4 PROTECTION

Protection consists of a variety of methods to defend coastal assets against the sea (erosion and flooding). It can take different forms, ranging from 'hard' methods, such as dikes, rip-rap, walls, gabions and groynes, to 'soft' or flexible methods, such as beach nourishment, revegetation and dune reprofiling, which allow coastal processes to resume naturally.

Data on the length and type of coastal protection by 'hard methods' tends to be incomplete and commonly outdated for most of the East Coast region (e.g., Bérubé, 1993; Bérubé and Thibault, 1996; Breau, 2000; Dubois et al., 2005; Bernatchez et al., 2008a; Catto, 2012). The exception is Prince Edward Island, where the entire coast was mapped by Davies (2011). Hard-protection approaches have been used for a long time, and estimates of the percentage of coast protected is usually less than 15% within local studies. Rip-rap (i.e., heavy stone or concrete) is by far the most widespread method employed. Other common types of hard protection structures in the East Coast region are seawalls of concrete or wood, bulkheads (i.e., gabions, sheet piling or wood cribs), revetments (i.e., using various materials to cover the coastal slope) and groynes made of stone, concrete blocks or wooden stakes driven in beach (Figure 22). In proximity to ports and harbours, jetties, groynes and breakwaters are the dominant structures and consist mostly of concrete dolosse or tetrapods, or heavy stone (Jennings et al., 2008).

Older homemade defence structures are still found at some locations, but their use is declining in favour of hard engineered structures (Bérubé and Thibault, 1996). Hard-protection measures for coastal defence are used to protect public infrastructure (i.e., harbours, port areas, roads and municipal frontage) and are also used by private landowners to protect their land and property from erosion. The number of individual coastal defence structures far exceeds the

FIGURE 22: Coastal-protection structures commonly used in the East Coast region (*adapted from* Jennings et al., 2008): **a)** riprap, Malagawatch ancestral burial grounds, southwestern Bras d'Or Lake, NS (S. O'Carroll, Geo Littoral Consultants); **b)** seawall, Eel River Bar First Nation, northeastern New Brunswick (D. Bérubé, New Brunswick Department of Energy and Mines): **c)** revetement, Mispec, southwestern New Brunswick (D. Bérubé, New Brunswick Department of Energy and Mines); **d)** bulkhead, Maria, Gaspésie, QC (Laboratoire de dynamique et de gestion intégrée des zones côtières–Université du Québec à Rimouski [UQAR]); **e)** groyne, Paspébiac, Gaspésie, QC (Laboratoire de dynamique et de gestion intégrée des zones côtières–UQAR); and **f)** breakwater, Pointe-Lebel, north shore of the St. Lawrence estuary, QC (Laboratoire de dynamique et de gestion intégrée des zones côtières–UQAR).

number of ports and small-craft harbours along the northern and eastern coasts of New Brunswick (Figure 23; Breau, 2000). On Quebec's North Shore, only one-third of the 91 km of artificial coasts mapped were attributed to port and harbour activities, with the remainder being public and private coastal protection (Dubois et al., 2005).

The total length of defence structures on the coast steadily increased, sometimes exponentially, during the period covered by aerial photographs. In southeastern New Brunswick, O'Carroll et al. (2006) documented that coastal armouring was 10 times greater in 1971 than in 1944, and 22 times higher in 2001 than it was in 1971.

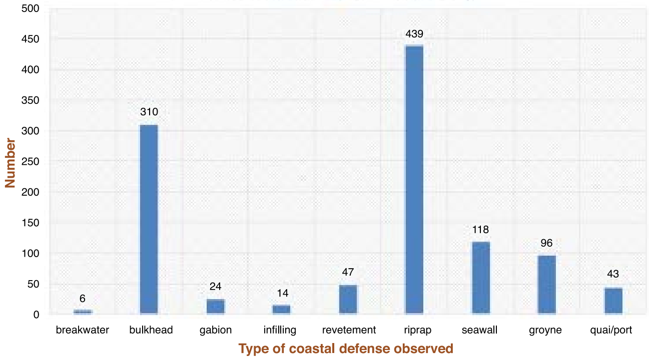

FIGURE 23: Inventory of coastal defence structures along the northern and eastern coasts of New Brunswick (Breau, 2000).

Similar trends have been observed for coastline armouring in the area of Percé (Péninsule de la Gaspésie, QC) and the residential areas surrounding Sept-Îles (Bernatchez and Fraser, 2012). Coastal armouring in the vicinity of Sept-Îles increased the most between the 1970s and the 1990s, and has since slowed considerably.

If hard-protection measures are not properly designed, placed and maintained, they can result in maladaptation: rather than diminishing vulnerability, they can actually worsen the situation, particularly for adjacent landowners. Among the most common negative effects are changes in the local sediment budget, which can result in accelerated erosion downstream, contributing to sand deficit or activating sand transfers. For these reasons, development of new sand-trapping measures such as groynes are highly restricted on crown land in New Brunswick (New Brunswick Department of Natural Resources, 2014). Other localized effects include the lowering, and sometimes the loss, of beaches and flats in front of the seawall (Bernatchez et al., 2008b, 2011; Bernatchez and Fraser, 2012). Lowering of the foreshore increases vulnerability to inundation. During storm events, surges increase the depth of water, allowing higher, more energetic waves to reach the shore. These situations can result in overtopping of protective structures such as dikes and seawalls (Bernatchez et al., 2011).

Hardening of the coastline by rigid, linear, coastal-protection structures can also lead to rapid loss of biodiversity and contribute to coastal squeeze by trapping coastal habitats and ecosystems between the rising sea and landward man-made barriers (Section 4.8). Another disadvantage of hard-protection measures is that they are generally irreversible. Once heavy stone or concrete structures are in place, it can be difficult to change the strategy of coastal protection because removal of the structures can be very expensive and often leaves the coast in an increased state of vulnerability until the equilibrium of the natural state is restored. In instances where coastal infrastructure cannot be removed, properly designed engineering approaches are warranted.

Soft-protection methods have only been used infrequently in the East Coast region. One example is the use of sand from the dredging of fishing harbours by the Quebec Department of Transportation to nourish beaches along roads threatened by erosion on the Îles de la Madeleine (Case Study 5). This method has adequately protected the roads since 2007 with no observed impact on the environment. The sand has the same characteristics as that of the local beach, since it comes from the nearby longshore drift. This reuse of dredged sand is an example of alternatives to hard protective structures. Mixed methods can also be used to reduce the wave energy, such as degradable groynes reloaded with sand (Figure 24), sand-dune–trapping devices, or protection and/or replanting of beach grass (Restore America's Estuaries, 2015).

6.4 IMPLICATIONS AND FUTURE DIRECTIONS

There are considerable opportunities in the East Coast region to increase the capacity for adapting to climate change and implementing effective adaptation measures to address coastal risks. Basic steps include increasing awareness, engaging and empowering stakeholders, reviewing and adjusting legislation and codes of practice where appropriate, enhancing interjurisdictional collaboration, and addressing regional and local differences in adaptive capacity. Adaptation is fundamentally a social process that leads to modification of long-standing habits. Progress has been made. As an example, recently developed guidelines for engineers recognize that the return period of extreme events changes over time.

Most coastal-management practices in the East Coast region were implemented before climate change was recognized as an issue and the concept of climate change adaptation was developed. The most common approaches to address coastal erosion and storm-surge flooding have been the use of hard protection methods and retreat from areas at risk. As a result of changing climate, the East Coast region is facing new challenges and will need to consider new ways of managing the associated risks. Coastal-adaptation researchers and practitioners worldwide have reported on the diverse challenges related to conflicting uses, financial fairness, integration and consultation processes, development, management of uncertainty, perceptions, political will and leadership, and regulatory framework and governance structure.

Examples of innovative ways to address these challenges are emerging. For example, with respect to consultation processes, Quebec has established a series of regional groups that serve as forums for gathering key participants around issues of managing multiple uses in the coastal areas of the estuary and Gulf of St. Lawrence (Ministère du développement durable, de l'Environnement, de la Faune et des Parcs du Québec, 2012). Ultimately, society will have to decide what constitutes sustainable development of the coast. Where cost-benefit analyses have been undertaken, there is evidence that decisions to retreat from the coast, and/or to use soft protection methods, are generally more productive in the long term. Ongoing economic analysis will also contribute to the selection of appropriate adaptation options. Where major infrastructure already exists, or where large populations are already settled in risk areas, the use of hard protection options may be more appropriate.

FIGURE 24: Hybrid living shoreline on the Shubenacadie River, Bay of Fundy, NS, illustrating gabion basket planted with marsh vegetation to reduce erosion scour. *Photo courtesy of V. Leys, August 2015.*

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APPENDIX A

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

Projected relative sea-level changes to 2100 are provided here for 19 locations shown on the accompanying map (Figure A1) for the East Coast region (*after* James et al., 2014, 2015; Section 3.1 and *see* Chapter 2 for details of projections). The sea-level projections (Figure A2) are based on the IPCC Fifth Assessment Report (Church et al., 2013) and were generated using vertical crustal motion derived from GPS observations.

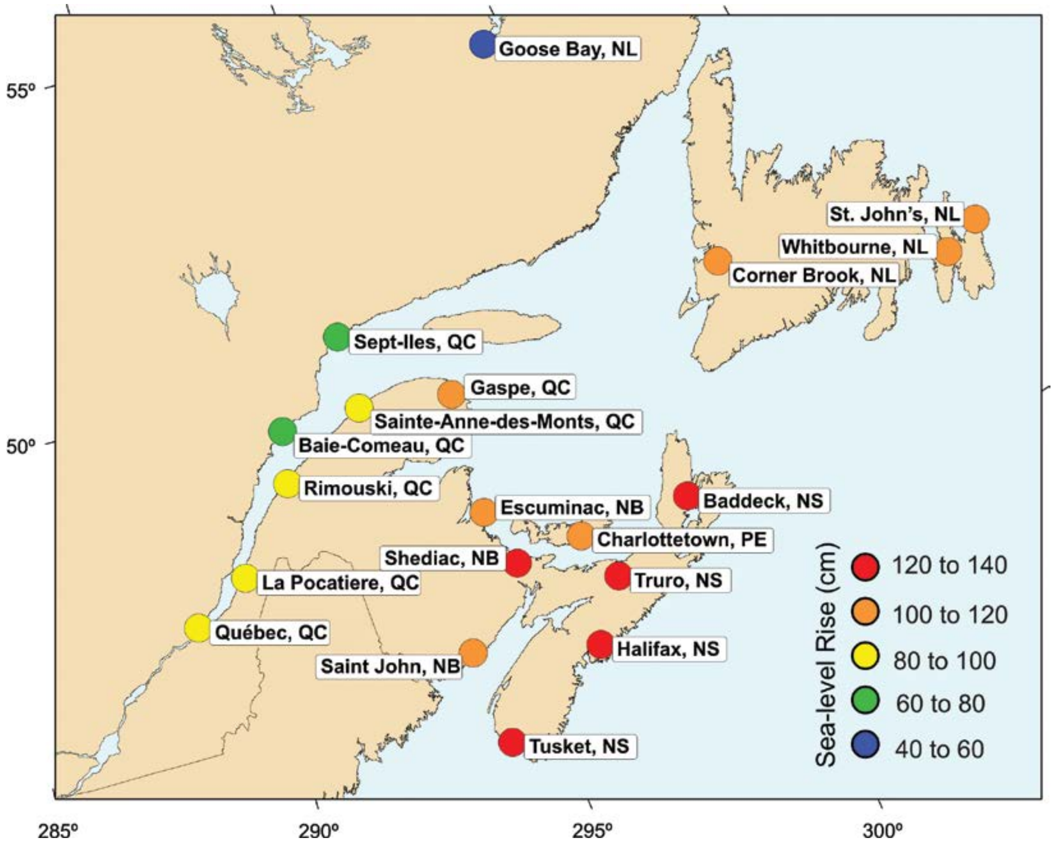

FIGURE A1: Locations for which sea-level projections are provided through the 21st century (Figure A2). Dots are colour coded to indicate the projected sea-level change at 2100 for the 95th percentile of the high-emissions scenario (RCP8.5; *after* James et al., 2014, 2015).

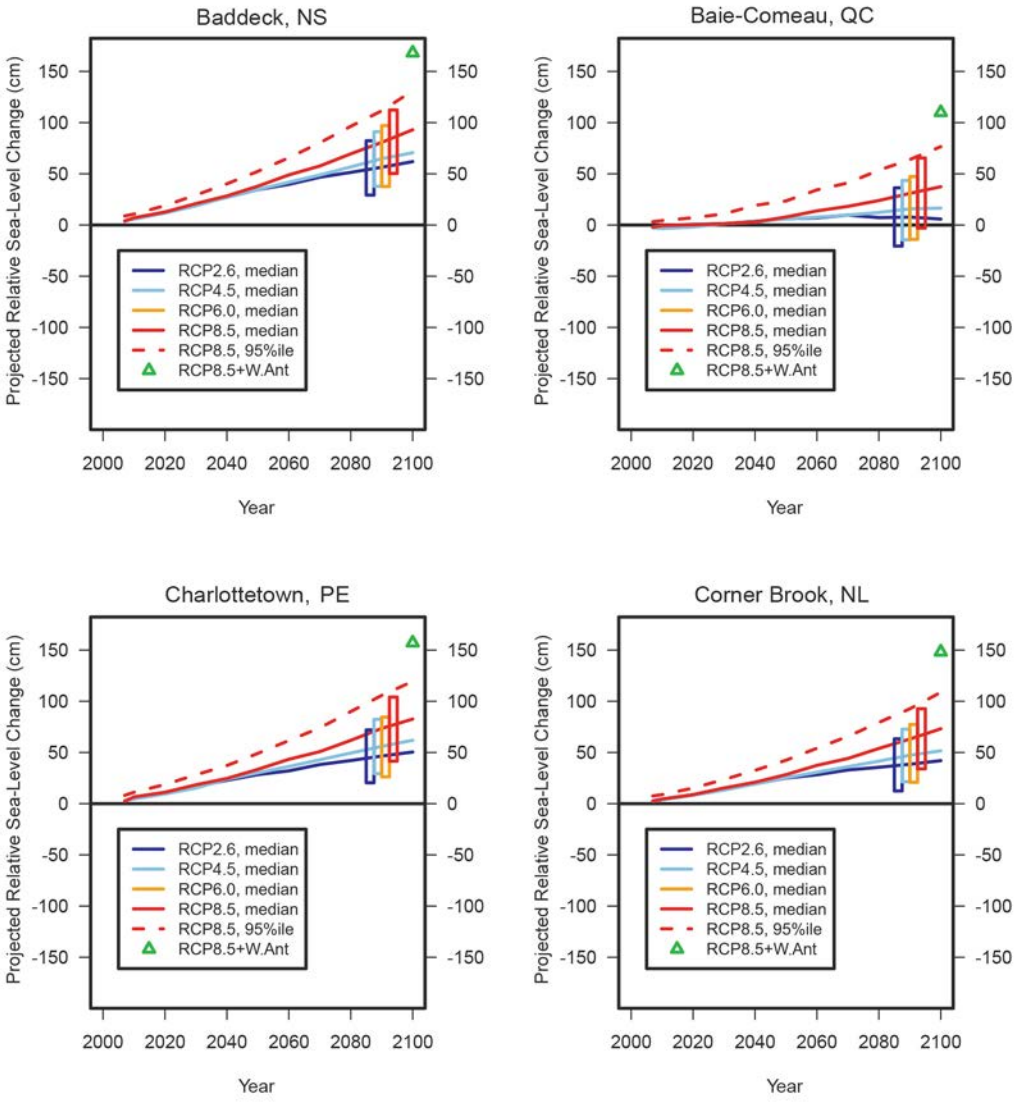

FIGURE A2: Projected relative sea-level changes through the 21st century for selected locations in the East Coast region (*after* James et al., 2014, 2015). RCP2.6 is the explicit emissions-reduction scenario, RCP4.5 is business as usual and RCP8.5 is high emissions. The projected value at 2100 is given for an augmented scenario, in which the West Antarctic Ice Sheet contributes an additional 65 cm to the median projected value of the high-emissions scenario (RCP8.5+W.Ant; green triangle). Rectangles show the 90% confidence interval (5–95%) of the average projection for the period 2081–2100 and include RCP6.0. The rectangles are staggered for clarity of presentation but pertain to the midpoint time of 2090. The dashed red line gives the 95th percentile value for the high-emissions scenario.

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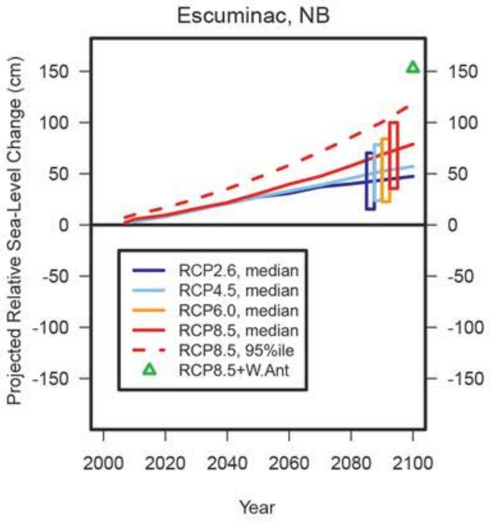
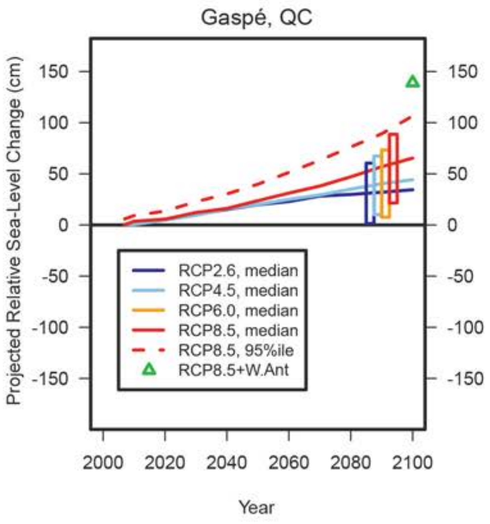
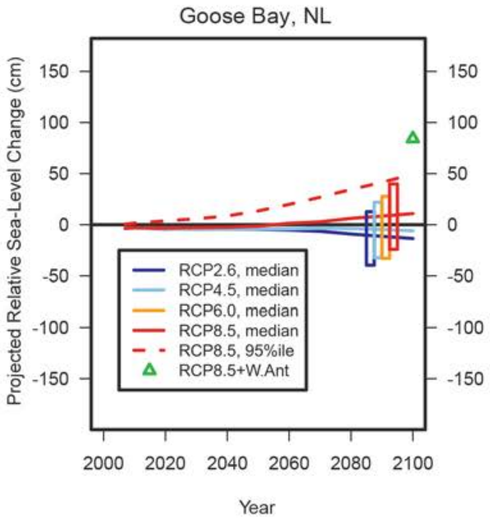
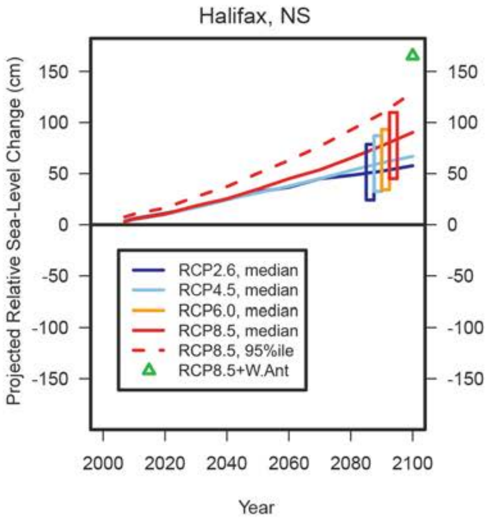
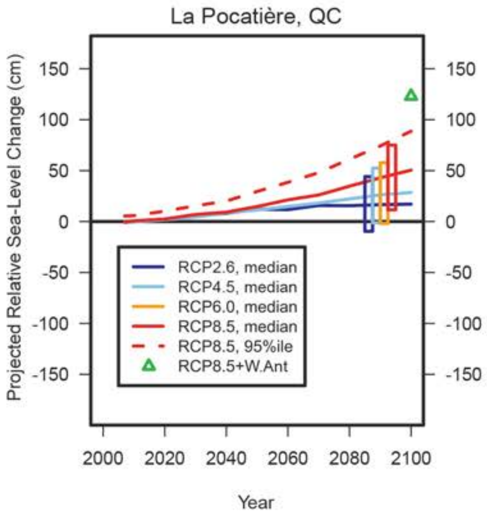
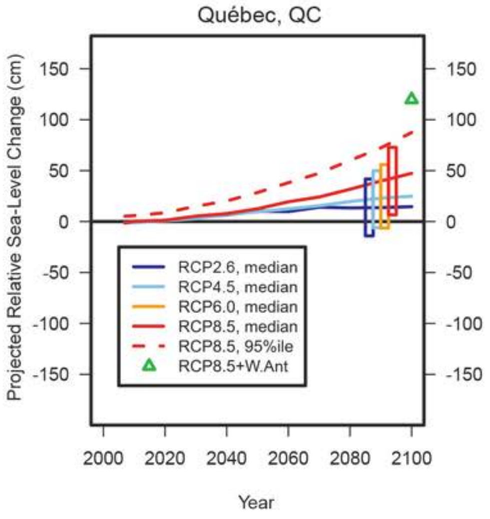

Escuminac, NB


Gaspé, QC


Goose Bay, NL


Halifax, NS


La Pocatière, QC


Québec, QC

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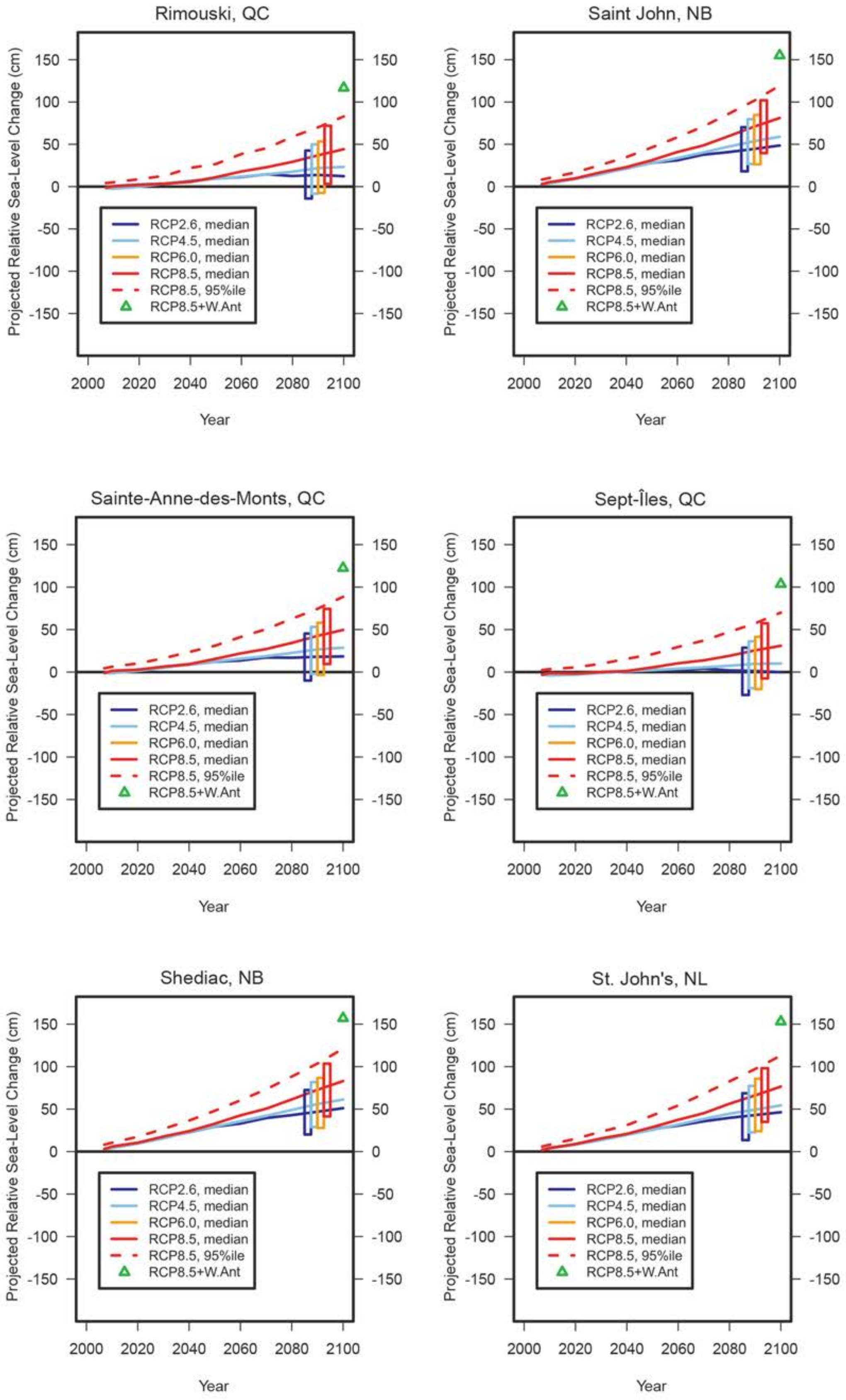
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Saint John, NB

Sainte-Anne-des-Monts, QC

Sept-Îles, QC

Shediac, NB

St. John's, NL

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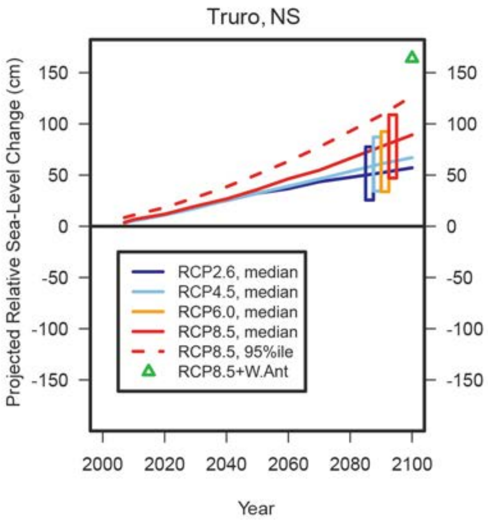
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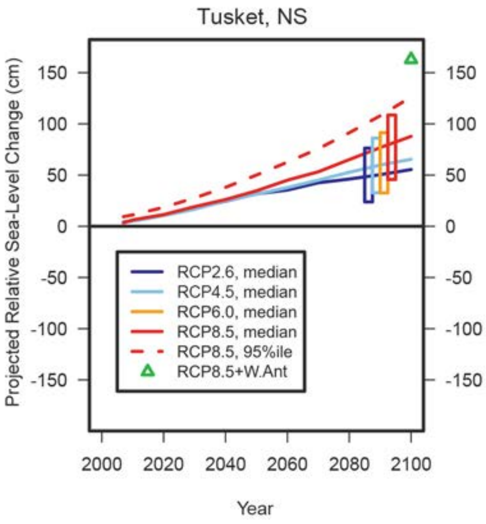
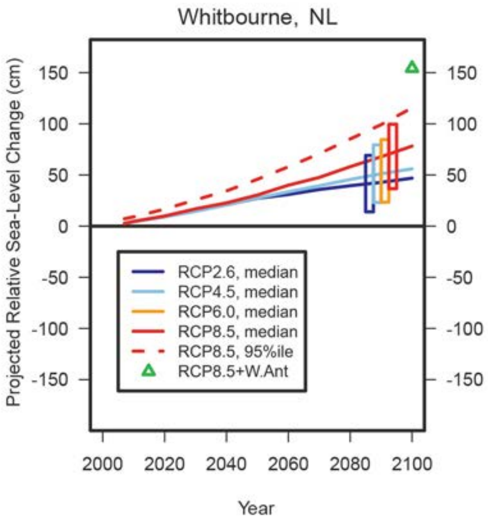

Tusket, NS


Whitbourne, NL