

Key Topic 4: Policies and Programs for Adapting to a Changing Climate

12. Explain how various levels of government, non-governmental organizations, and individuals are involved in mitigating and adapting to climate change at the local, national, and international levels.
13. Describe innovative technologies and programs designed to combat climate change.
14. Explain the importance of primary resource sectors (forestry, agriculture, fisheries) to the economy of New Brunswick.
15. Describe the unique challenges faced by regions largely dependent on primary resources, and how climate change influences these challenges
16. Explain how to best apply climate change risk assessment and adaptation measures in regions with primary resource dependent economies.

Study Resources

Resource Title	Source	Located on
VIDEO: UN Sustainable Development Goals – Overview – CLICK LINK	<i>United Nations, 2018</i>	Page 112; 2 Minutes
Federal Adaptation Policy Framework for Climate Change	<i>Government of Canada, 2016</i>	Pages 113-118
Memorandum of Cooperation between the Government of Canada and the Government of the State of California of the United States of America concerning Climate Action and Nature Protection	<i>Government of Canada, 2022</i>	Pages 119-123
How Can Technology Help Combat Climate Change	<i>World Economic Forum, 2022</i>	Pages 124-127
Carbon Sequestration	<i>University of California – Davis, 2021</i>	Pages 128-132
A Profile of the Natural Resource Sector in New Brunswick	<i>NBJobs.ca, 2021</i>	Pages 133-141
Atlantic Provinces, Regional Perspectives Report	<i>Government of Canada, 2022</i>	Pages 142-150
Perspectives on Canada’s East Coast region; in Canada’s Marine Coasts in a Changing Climate	<i>Savard, J.-P., van Proosdij, D. and O’Carroll, S.; (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer Clarke; Government of Canada, Ottawa, ON; 2016</i>	Pages 151-189

Climate Change: Impacts on Forests	<i>Government of Canada, Natural Resources Canada (NRCan), 2020</i>	Pages 190-192
Canada's Partnership with Indigenous Peoples on Climate	<i>Environment and Climate Change Canada, 2022</i>	Pages 193-195
Renewable Energy Brings About Improvement In People's Livelihoods and Helps Fight Climate Change	<i>International Model Forest Network (IMFN), 2019</i>	Pages 196-198

Please Note: Hyperlinks found in text are not considered required reading; however, included video links are required to watch.

Study Resources begin on the next page 



 **SUSTAINABLE DEVELOPMENT GOALS**



Federal Adaptation Policy Framework for Climate Change

The Federal Adaptation Policy Framework guides domestic action by the Government of Canada to address adaptation to the impacts of climate variability and change. It sets out a vision of adaptation in Canada, objectives, roles of the federal government, and provides criteria for setting priorities for action. While adapting to climate change requires a long-term vision, this framework is aimed at targeting medium-term strategies.

Climate change impacts are already being observed across a wide range of federal services, programs, policies, and regulations and all must adapt. Implementation of this framework is intended to result in adaptation considerations being proactively and explicitly included in federal processes, in order that adaptation planning, and programming occurs as part of ongoing federal activities. The framework will support decision making in federal organizations' planning of adaptation elements in their programming and in central agencies reviewing of programs with adaptation elements. It calls for consideration of climate change impacts, without prescribing how or when to adapt.

This domestic framework will also serve as input to the development of Canada's international policy on climate change adaptation.

Context

The Earth's climate is already changing, and it will continue to change in the medium-term, regardless of the effectiveness of global measures to reduce greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) agrees that the rate of change will exceed that to which humans or ecosystems can easily adjust without explicit planning and action by decision-makers.

The impacts of a changing climate are evident in every region and sector across Canada. Higher temperatures, declining sea and lake ice, diminishing glaciers, melting permafrost, more heat waves, more violent storms, and increased coastal erosion are some of the changes being observed. The North is particularly vulnerable to the impacts of climate change, as they are experiencing changes that are more extreme and occurring at a faster rate than the rest of Canada. The impacts of many recent severe weather events demonstrate that Canadian communities, critical infrastructure and human health are vulnerable to climate change. Some of the most widespread impacts in Canada are related to waterways and water resources, which affect agriculture, fisheries, energy production, transportation systems, municipalities, and recreation. Climate change impacts are not only physical; they can have long-lasting economic, social, environmental, and human health effects. While there will be negative impacts as a result of climate change, Canada will also experience benefits such as longer agricultural and ice-free shipping seasons and expanded tourism and recreation opportunities.

Canadians need to adapt to the changing climate by taking action to reduce negative consequences and to take advantage of new opportunities that the changes may bring. Climate-sensitive decisions can no longer be based solely on historical climate data.

According to the IPCC, adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities. Adaptation requires making decisions in the face of the uncertainty inherent in the prediction of future climate change and variability, in the cumulative impact of climate impacts, and of future socio-economic challenges and opportunities. Adaptation involves reducing vulnerability and strengthening resilience to climate change and variability. Adaptation is best guided by incorporating new scientific information (e.g., future climate models and scenarios) into existing risk management processes.

Vision statement

Recognizing the need to adapt to climate change, the wide variation in climate impacts across Canada, and the many groups that are involved in adaptation, the Government of Canada adopts the following vision:

Canada is resilient to a changing climate by successfully adapting to the challenges and opportunities, and ensuring the health, safety, and security of Canadians and Canada's environmental, social, and economic wealth in a long term and sustainable manner.

Objectives

The following are the objectives of the Federal Adaptation Policy Framework:

1. Canadians understand the relevance of climate change and associated impacts on their quality of life.
2. Canadians have the necessary tools to adapt to climate change effectively.
3. The federal government, as an institution, is resilient to a changing climate.

The federal role

Given the broad health, environmental, social, and economic impacts of climate change, the federal government must take action to ensure that it effectively integrates climate change considerations into its own programs, policies, and operations and facilitates action by others. These roles are accomplished by:

1. Generating and sharing knowledge

The Government of Canada plays a crucial ongoing role in the generation and provision of scientific information to support evidence-based decision making related to climate change impacts and adaptation. In some cases, the federal government hosts knowledge and expertise

not found elsewhere in Canada. This includes a range of activities, such as periodic national assessments of climate change, development of innovative new technologies and practices, ongoing environmental monitoring, research in specific areas (e.g., climate change projections, climate change effects on forests, and transportation infrastructure), and support for and engagement with stakeholders in the development of tools for adaptation. This role capitalizes on federal strengths in science and technology that are not replicated outside the Government. It is also essential to the understanding of critical issues and the ability of stakeholders to develop and apply effective responses.

The Government of Canada is well positioned to mobilize economies of scale to generate and deliver fundamental knowledge and information that can be applied across the country. Sharing information, both within the federal government, the international community, and with other external stakeholders (e.g., academia) will increase awareness of climate change impacts, assist with capacity building, and reduce adaptation costs in all regions and sectors. By participating in the generation of new information and tools, the federal government will ensure that this is made public.

Knowledge of climate variability, change, impacts, and adaptation options is a fundamental input to both internal and external adaptation. Further research and modeling to address knowledge gaps, such as socioeconomic considerations and refining information at local scales, will lead to better and more targeted adaptation. Although our climate variability and change knowledge is incomplete, there is now enough information to implement adaptation measures.

2. Building adaptive capacity to respond and helping Canadians take action

The federal government plays a key role in helping to build the capacity of the private sector, other levels of government, communities, and organizations to assess and manage the risks and complexities of a changing climate and to take effective and sustainable action. These efforts should continue. The federal government is particularly well-positioned to support the development and dissemination of climate change information, guidance, and tools that help Canadians to adapt.

The federal government's ability to facilitate collaboration amongst many different stakeholders can be leveraged to build broad-based awareness and understanding of climate change in order to motivate and promote action at all levels across the country. For example, the government could engage stakeholders and facilitate expert discussions on assessing the need for adaptation and ways to adapt within their domains and providing decision-making tools that others can use¹. Further, collaborative action across governments, economic sectors, communities, and disciplines can increase the effectiveness and efficiency of adaptation measures.

3. Integrating adaptation into federal policy and planning (mainstreaming)

Managing the potential impacts of climate change is also part of an organization's risk management considerations. According to the Treasury Board of Canada Secretariat's

Framework for the Management of Risk, “Effective risk management equips federal government organizations to respond actively to change and uncertainty by using risk-based information to enable more effective decision-making.” While there are some anticipated benefits, impacts from climate changes are projected to be mostly negative and could affect all aspects of Canadian society. As such, it is the responsibility of each federal organization to apply its experience in risk management to the climate change issues that could affect its continued ability to deliver on its mandate. In this way, federal organizations can build the capacity to proactively manage uncertainty that stems from climate change and make informed decisions about how best to minimize negative impacts and maximize opportunities.

As Canada’s largest organization, with operations in all regions of the country, an effective way for the federal government to advance adaptation efforts across Canada is to lead by example, specifically by building resilience into federal assets, programs and services against the impacts of climate variability and change. This means ensuring that climate change considerations are integrated into federal activities, such as policy and planning processes. Factoring climate variability and change into policy, programs, and operations is one of the most important ways the government can contribute to adaptation and is consistent with the government’s risk management approach of enhancing the protection of public assets and resources and strengthening planning and decision making. Experts agree that integrating climate variability and change information into policy, planning, and decision-making is more effective and more cost-efficient than addressing adaptation in isolation.

Via integrating adaptation into federal policy, planning, and operations adaptation planning and decision-making will become part of ongoing management processes, rather than an independent policy or program domain, and will be accomplished within existing government structures. By integrating adaptation, the government itself adapts, and in so doing can mobilize its authorities, investments, and economic instruments in support of adaptation actions across the country. Integration will require building internal capacity, disseminating information, and developing new knowledge.

Criteria for identifying federal priorities

In carrying out the federal role, it is recommended that federal departments and agencies give consideration to the following criteria when identifying climate change adaptation priorities:

1. Nature of impacts and vulnerability

Adaptation should be a priority where negative impacts are most severe or beneficial impacts are of the greatest potential. Severe impacts can occur in a number of ways, such as via a large impact on a small group (e.g., northern communities), or a small impact on a large group.

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity². The nature of the resulting profile of potential

vulnerabilities is an important input to adaptation decision-making. There may be thresholds where risks from impacts change, irreversible losses occur, or where impacts cease to be beneficial.

2. Appropriateness of federal action

Several criteria are useful for guiding priority setting and decision making for determining when and where it is appropriate for the federal government to act. These criteria should be considered in the order they are presented.

I. Unique federal role and responsibility

The nature of federal responsibility is a factor in setting priorities. Greater attention should be accorded to areas of sole federal responsibility (e.g., First Nations and Inuit, oceans, inter-provincial, and international matters), where the federal government has fiduciary or other direct responsibilities, is better positioned to act than other groups (e.g., gathering and disseminating climate change adaptation information, guidance, and tools), or has legislative authority (e.g., mainstreaming adaptation into federal policy and planning).

II. Unique federal capabilities

Greater consideration should be accorded to areas in which the federal government has the levers, assets, and capabilities that others do not have to generate knowledge, products, and services (e.g., decision-making tools, future climate data) necessary for adaptation in Canada.

For example, at present, the federal government operates some unique climate, oceans and freshwater monitoring networks and has expertise unparalleled in Canada in climate modeling. The resulting environmental data are key inputs to adaptation planning in organizations across Canada.

III. Timeliness of action

It is important to take cost-effective action in situations where inaction would result in increased negative impacts, including associated costs or forgone opportunities. Implementing adaptation should be a priority when existing provisions lock-in conditions inadequate for predicted future changes in climate. For example, costs associated with future climate related failures in infrastructure could potentially be avoided by changing current infrastructure design protocols to become more resilient to predicted future changes in climate.

IV. Effectiveness of action

Federal action on adaptation should be directed towards areas where intervention is effective and efficient. Indicators of effectiveness and cost efficiency are collaboration, which leverages federal investment, and broadly applicable products, services, policies, or actions.

3. Mainstreaming ability

Climate change adaptation must become the new business-as-usual for individuals and organizations across Canada. Knowledge and tools must support independent action and the integration of adaptation into existing objectives, strategies, policies and processes at all levels and stages. Policies and programs will need to be evaluated and revised as conditions change over time and new knowledge is generated.

4. Collaboration potential

The federal government should focus on priority-driven partnerships in order to integrate plans and actions among partners and support a coherent, targeted response in the key domains of health and communities, the economy, infrastructure, and natural systems.

Memorandum of Cooperation between the Government of Canada and the Government of the State of California of the United States of America concerning Climate Action and Nature Protection

The Government of Canada and the Government of the State of California, hereinafter referred to as “the Participants”,

Considering that the twin challenges of climate change and biodiversity loss are a global threat to the lives and livelihoods of individuals and communities, and that there is an urgent need for collaboration on solutions to mitigate and adapt to climate change, as well as to prevent and halt biodiversity loss;

Considering that vehicles and transportation fuels are a significant source of greenhouse gas and air pollutant emissions in both Canada and California and, that cutting transportation emissions is one of the most readily achievable and economically beneficial ways to mitigate climate change, while building cleaner and more resilient communities and economies;

Considering that the Department of the Environment of Canada (Environment and Climate Change Canada - ECCC) and the California Air Resources Board have an existing Memorandum of Understanding to promote and carry out cooperative activities on policy and regulatory measures that reduce emissions of greenhouse gases and air pollutants including from: vehicles, engines and fuels;

Considering that there are further opportunities to collaborate and share information on light-, medium-, and heavy-duty vehicles, off-road equipment, clean and renewable fuel standards and charging infrastructure;

Considering that the development, adoption and scale up of clean technologies such as hydrogen, carbon capture, utilization and storage, clean energy, among others, is critical to meet their emission reduction goals;

Considering that Canada and California are implementing a range of complementary voluntary and regulatory actions spanning the plastics lifecycle in order to address the threats of plastic waste and pollution, including microplastics, on the health of the environment and ecosystems, including wildlife, rivers, lakes and oceans, and to accelerate the adoption of innovative technologies and advance the transition towards a circular economy for plastics that will reduce pollution and have positive economic impacts;

Considering that both Canada and California are experiencing more frequent extreme weather events, such as wildfires, stronger storms and droughts, eroding coastlines and floods, as well as experiencing increasing social and economic losses from current and future impacts of

climate change and that urgent action is needed to adapt and build resilience, including through the use of nature-based solutions;

Considering that Canada is developing a National Adaptation Strategy and California has recently updated its Climate Adaptation Strategy;

Considering that both Canada and California are working to accelerate action on biodiversity conservation in the face of the climate crisis, in particular through Canada's commitment to conserve 30 percent of its lands and waters by 2030 and California's similar commitment to conserve 30 percent of its lands and coastal waters by 2030;

Considering that Indigenous knowledge, including customary practices and cultural values, is essential in the fight against climate change, land degradation and biodiversity loss and that both Canada and California have committed to engaging Indigenous peoples;

Considering that further collaboration between the Government of Canada and the Government of California would help them to achieve their climate change mitigation, adaptation and biodiversity objectives;

Have reached the following understanding:

1. Objective

- a. The objective of this Memorandum of Cooperation (MOC) is to establish a flexible framework for the Participants to promote and carry out cooperative activities in order to advance their respective policies and regulatory measures aimed at reducing pollution, adapting to climate change and conserving nature according to the Participants' respective competencies and based on principles of equality, reciprocity, information exchange and mutual benefit. In doing so, the Participants share the following common objectives:
 - i. Facilitate collaboration on their zero emission transport goals, including light-duty vehicle ZEV sales and emission reduction targets, related incentive programs, and efforts to reduce the carbon intensity of fuels and to reduce and eliminate emissions from medium- and heavy-duty vehicles and off-road engines;
 - ii. Promote the use of clean technologies to meet their emission reduction and Canada's net zero goals, California's carbon neutrality and to build resilience;
 - iii. Share information, lessons learned and best practices on climate adaptation, nature-based solutions, circular economy and plastics to support their respective policy and regulatory development.

2. Areas of cooperation

- a. The Participants intend to advance their respective policies and regulatory measures aimed at preventing pollution, adapting to climate change and conserving nature through initiatives focused particularly on the following areas of cooperation:
 - i. Clean Transportation;

- ii. Clean Technology and Innovation;
- iii. Biodiversity Conservation;
- iv. Climate Change Adaptation;
- v. Circular Economy, including Plastics Management;
- vi. Any other areas of cooperation they may jointly decide upon.

3. Cooperative activities

- a. The Participants may carry out the following cooperative activities:
 - i. Collaboration and sharing of technical information and/or best practices on regulatory development and administration, research, and policy and program development related to their respective regulations for greenhouse gas and other emissions and ZEV targets for light-, medium-, and heavy-duty vehicles and off-road equipment, as well as incentive programs, and low-carbon fuels among others;
 - ii. Collaboration and sharing of information and/or best practices related to advancing innovation, investment, adoption and scale up of clean technologies, including measures that drive emissions reductions by 2030 and net zero emissions by mid-century, as well as exploring collaboration opportunities with academia and private sector and to exchange information on strategies with respect to emerging clean technologies;
 - iii. Sharing of information and best practices on biodiversity conservation in the face of the climate crisis, such as: understanding the impact of climate change and other stressors on biodiversity; protecting areas that are important for biodiversity, including climate refugia; accelerating biodiversity conservation efforts; conserving 30% of lands and waters by 2030; developing robust monitoring and evaluation programs to track progress toward biodiversity conservation goals; and meaningfully engaging stakeholders and indigenous peoples in biodiversity conservation (including approaches for considering and co-applying Indigenous Knowledge where made available by and with consent of knowledge holders);
 - iv. Sharing of information and best practices to advance climate adaptation and build resilience to the impacts of climate change such as rising sea levels, flooding, extreme heat, wildfires and droughts, including, for example, knowledge exchange on nature-based solutions and their potential benefits such as public health and safety, economic prosperity, food and water security, and carbon sequestration;
 - v. Sharing of information and best practices on circular economy initiatives, approaches and methods beyond traditional recycling;
 - vi. Collaboration and seeking areas of harmonization in policies and regulations related to circular economy as well as reducing plastic waste and pollution, where appropriate, to prevent plastic pollution including from microplastics and commonly littered single-use plastics; address misinformation regarding the recyclability and compostability of plastics; advance plastic pollution science and performance measures or indicators; strengthen demand for

recycled plastics; and share information and best practices on research and policy measures such as the implementation of strategies and action plans.

4. Implementing authorities

The Participants respectively designate ECCC and the California Environmental Protection Agency to establish a work plan to implement the objectives of this MOC and commit to report back on progress annually.

5. Points of contact

a. The Participants designate the following as their point of contact for communication and information exchange, as well as any notice required to be submitted under this MOC:

i. For ECCC:

Jeanne-Marie Huddleston,
Director General,
Bilateral Affairs and Trade Directorate,
International Affairs Branch

ii. For the California Environmental Protection Agency:

Shereen D'Souza,
Deputy Secretary for Climate Policy and Intergovernmental Relations

6. Availability of personnel and resources

a. The Participants understand that:

i. this MOC does not involve the exchange of funds, nor does it represent any obligation of funds by either Participant;

ii. all costs that may arise from activities covered by, mentioned in, or pursuant to this MOC are expected to be assumed by the Participant who incurs them, unless otherwise jointly decided upon in a separate instrument;

iii. all activities carried out pursuant to this MOC are subject to the availability of funds, personnel and other resources of each Participant.

b. The Participants understand that their personnel is expected to work under their respective orders and any other organization or institution to which the personnel already belongs, at all times maintaining any preexisting employment relationship only with them and the organization or institution, and not with any other Participant.

7. Respect of applicable laws

The Participants understand that they will carry out the activities and understandings outlined in this MOC in accordance with their respective laws.

8. Intellectual property

If, as a result of the activities developed in accordance with this MOC, intellectual property issues arise, the Participants intend to address them in a separate and appropriate instrument.

9. Differences in interpretation and application

The Participants intend to resolve any difference in the interpretation or application of this MOC through consultations.

10. Status

This MOC is a voluntary initiative and is not legally binding. In addition, the commitments in this MOC are not conditioned upon reciprocal actions by the other Participant; each

Participant retains full discretion over implementation of its commitments in light of the Participant's individual circumstances, applicable law, and policies; and each Participant is free to withdraw from this MOC.

11. Final dispositions

- a. This MOC is intended to take effect on the date of its signature by the Participants and to remain valid for five years. The Participants may extend this MOC upon their mutual written consent.
- b. The Participants may modify this MOC at any time upon their mutual written consent.
- c. Either Participant may, at any time, terminate this MOC by providing a written notice to the other Participant. A Participant who intends to terminate this MOC is expected to endeavor to provide notice of such withdrawal to other Participants 30 days in advance.
- d. The Participants understand that termination of this MOC is not expected to affect the conclusion of the cooperative activities that may have been initiated during the time MOC was in effect, unless the Participants jointly decide otherwise.

Signed in duplicate at Los Angeles on this 9th day of June 2022, in the English and French languages, both versions being equally valid.

For the Government of Canada

Steven Guilbeault
Minister of Environment and Climate Change

For the Government of the State of California of the United States of America

Jared Blumenfeld
Secretary for Environmental Protection

How Can Technology Help Combat Climate Change

Jul 12, 2021

Climate Change

- **After setting climate targets, countries and companies will need to quantify, reduce and monitor their emissions.**
- **This process can be complex, time-consuming and prone to errors, especially for novices.**
- **The right technology can simplify this process and make it more efficient, transparent and effective.**
- **Here are three ways climate change technology solutions – particularly AIoT.**

As society pressures leaders for a more environmentally-friendly agenda, governments responsible for [63% of world emissions](#) have committed to net zero with [corporate](#) net-zero commitments covering 12% of the global economy (representing \$9.81 trillion in revenue).

However, it is not uncommon to see large disconnects between targets and actual emissions – when the talk and the walk must go hand-in-hand in terms of effective emission-reduction progress. In June 2021, when the [G7](#) decided to make climate risk disclosure mandatory, seven of the most influential global economies indicated that carbon reporting and disclosures would play a vital role in ensuring that emission reduction targets are in fact met.

Setting a target is just the first step; the second is to understand and quantify the real emission baseline into measurable units. Next, a clear definition of the emissions reduction strategy must be built. Finally, near real-time monitoring of targets vs actual progress should be in place. Ultimately, if countries and companies are to achieve net zero, they need to monitor, reduce and, in some cases, offset the emissions they generate.

The journey can be complex for beginners; it can be time-consuming, very manual, and prone to errors. That should not prevent companies from joining the decarbonization wave. After all, beyond satisfying consumers and political leaderships, committing to net zero might also prove economical, as access to capital will prove increasingly difficult for those not embracing the energy transition. As 'carbon tax' or 'cap-and-trade' schemes become the most [likely](#) path forward, and as access to capital is reduced for those who fail to embrace the energy transition, early net-zero movers will have a competitive financial edge over laggards.

Carbon-management process

Carbon management can be broken down into three main categories: emission measuring and reporting, abatement, and offsetting.

1. Measuring and reporting carbon footprint

The first step is to measure carbon emissions. The carbon reporting process involves the collection of CO2 data, organising by emission type and geographical segment. The data is then

measured against internationally recognised carbon-accounting standards such as [GHG protocol](#) or [ISO 14064-1](#). Currently, emission data may be [obtained](#) through meter readings, purchase records, utility bills, engineering models, direct monitoring, mass balance, stoichiometry (the calculation of reactants and products in chemical reactions), or other methods for acquiring data from specific activities in the company’s value chain. Challenges associated with measuring and reporting commonly include the laborious data collection process, difficulty reviewing carbon footprints across business units and assets, as well as validating underlying assumptions of emissions.

2. Abatement planning and management

Abatement planning involves identifying key sources of emissions and implementing measures to reduce them. By categorising emissions in step one, businesses can then pinpoint and measure which processes emit the highest volumes of CO2 and optimise their carbon-abatement plan. To achieve this, abatement roadmaps set out targets and KPIs to reduce emissions, focusing on changing emission-heavy processes and implementing new technologies to reduce emissions. Due to the multiple variables that need to be considered in such planning, the process can be uncertain and complex. Furthermore, tracking the performance and progress of abatement programmes is laborious. Organizational challenges include a lack of both transparency regarding marginal cost-benefit of abatement programmes, and resources for managing and executing this abatement journey.

Net zero emissions target announcements

agreed in law, as part of an initiative, or under discussion

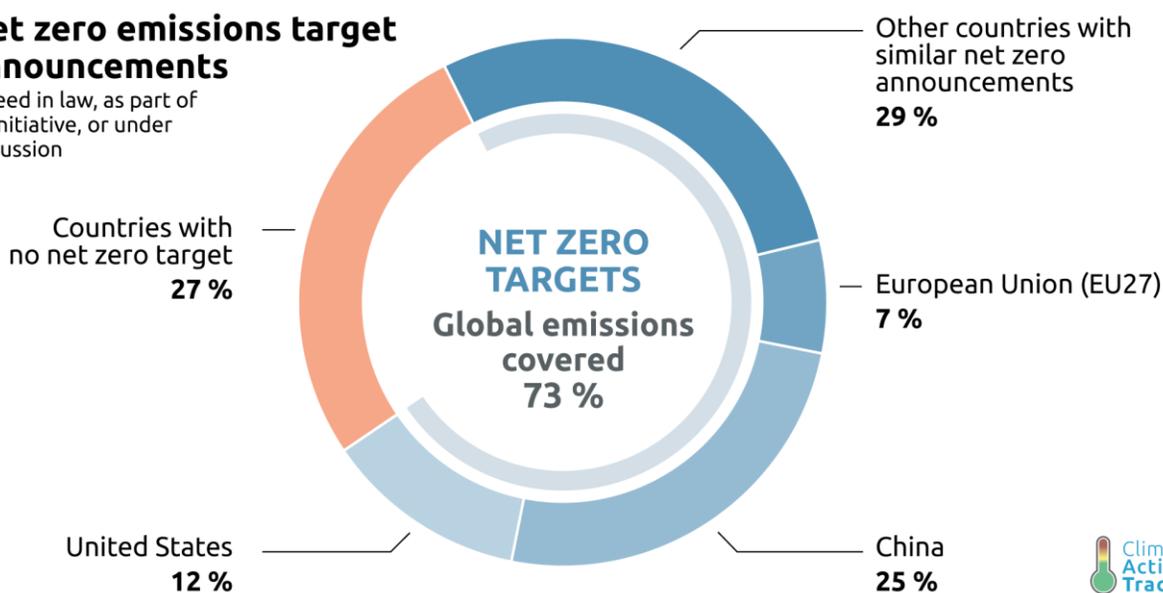


Image: Climate Action Tracker

3. Carbon offsetting

Carbon offsetting is considered the option of last resort once all abatement efforts and decarbonization investments have been exhausted. It is a way of taking responsibility for unavoidable carbon emissions by paying for others to reduce or absorb CO2. Multiple types of projects are used for carbon offsets, ranging from environmental projects such as reforestation,

to carbon-capture technologies and renewable energy production. [Carbon credits](#) are measurable, verifiable emission reductions and have been used as a means for governments and companies to offset carbon emissions. Further methods include the use of RECs (renewable energy certificates) to offset energy consumed from non-renewable sources. However, offsets also come with challenges, from accurate measurement to transparency and verification to ease of trade.

How technology can fight climate change

Artificial intelligence of things (AIoT) solutions are integral to tackling some of the challenges associated with carbon management. There are three main areas of focus to make carbon management more efficient, transparent and effective.

1. AIoT – integration into measurement and reporting

With a myriad of databases and systems involved with different carbon-producing assets, the labour required to simply categorise and organise the data from multiple business units and assets is immense. AIoT integration enables seamless sourcing of real-time activity level data and asset inventory data from a variety of systems. This provides an organization with the capability to efficiently structure, collect and transform data into reports for accurate emissions-monitoring and measurement, reducing overall efforts around data collection and enhancing data quality and report resolution.

2. Abatement intelligence – predictive analytics to simulate emissions over time

Abatement planning is a challenge primarily due to the lack of accurate measures for determining the emissions derived from certain processes. AIoT technology tackles this challenge by creating insights from real-time data to better predict process emissions. By analysing and learning through data from multiple processes, AIoT can refine the performance evaluation of abatement measures and optimise emissions predictions. Beyond optimising abatement strategies, this technology also lowers the overall marginal abatement costs.

3. Carbon offsetting and offset integration

Although a last resort, the carbon offset market plays an essential role towards achieving global net-zero emissions goals for countries and organizations, with an estimated addressable [market size of \\$200 billion by 2050](#). However, verification of carbon offsetting and difficulty in trading plagues the industry. Technology can support validation of RECs in near real-time and offer a marketplace for affordable and fast carbon offsetting. Offset integration would provide a global pool of offsets to an organisation, improving ease of trade and emissions planning, reducing organizational hassle, and optimising the timings of REC purchases and retirement.

Carbon management solutions are essential to meeting the G7's mandatory climate risk disclosures. More importantly, they provide the technology to actively manage and reduce carbon emissions and achieve the net-zero pledges made by governments and corporations. Driven by strong political, societal and economic agendas, carbon management solutions will be an integral part of emission reductions. For that, real-time measurement, abatement, and offset

integration will help ensure companies not only talk the talk but also walk the walk and transparently meet their net-zero targets.

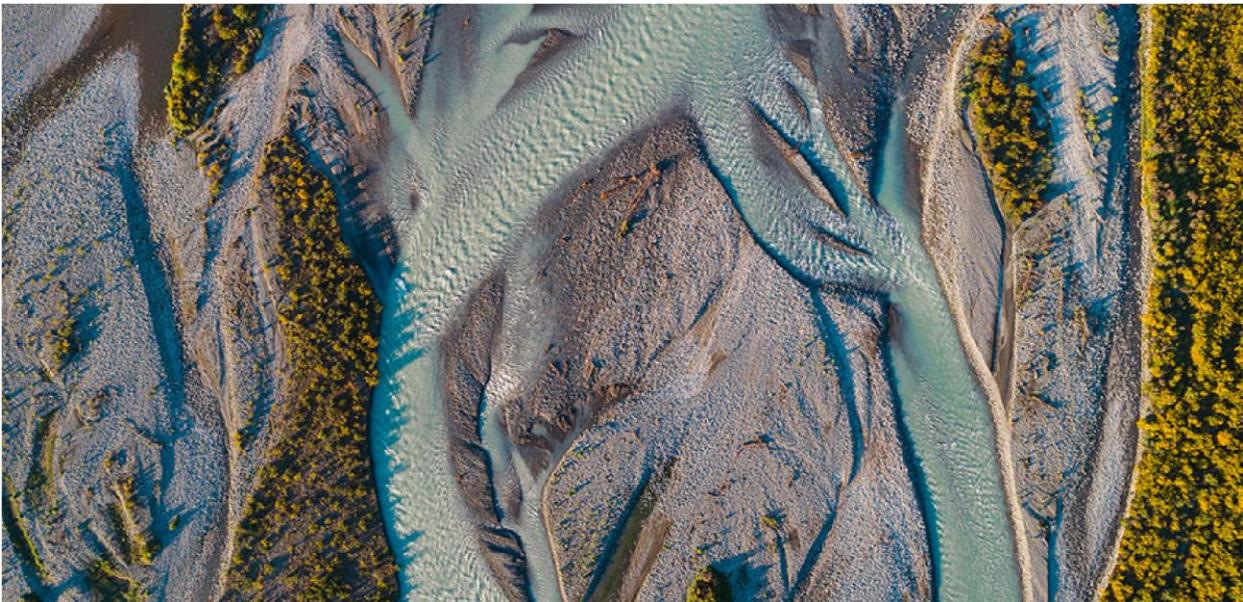
Carbon Sequestration

University of California – Davis, 2021

What is Carbon Sequestration?

Carbon sequestration secures carbon dioxide to prevent it from entering the Earth's atmosphere. The idea is to stabilize carbon in solid and dissolved forms so that it doesn't cause the atmosphere to warm. The process shows tremendous promise for reducing the human "carbon footprint." There are two main types of carbon sequestration: biological and geological.

What is Carbon?



In many ways, carbon is life. A chemical element, like hydrogen or nitrogen, carbon is a basic building block of biomolecules. It exists on Earth in solid, dissolved and gaseous forms. For example, carbon is in graphite and diamond, but can also combine with oxygen molecules to form gaseous carbon dioxide (CO₂).

Carbon dioxide is a heat trapping gas produced both in nature and by human activities. Man-made carbon dioxide can come from burning coal, natural gas and oil to produce energy. Biologic carbon dioxide can come from decomposing organic matter, forest fires and other land use changes.

The build-up of carbon dioxide and other ['greenhouse gases' in the atmosphere can trap heat and contribute to climate change.](#)

Learning how to capture and store carbon dioxide is one way scientists want to defer the effects of warming in the atmosphere. This practice is now viewed by the scientific community as an essential part of [solving climate change.](#)

Types of Carbon Sequestration

Biological

Biological carbon sequestration is the [storage of carbon dioxide in vegetation such as grasslands or forests](#), as well as in soils and oceans.

Biological Carbon Found in the Oceans



Oceans absorb roughly 25 percent of carbon dioxide emitted from human activities annually.

Carbon goes in both directions in the ocean. When carbon dioxide releases into the atmosphere from the ocean, it creates what is called a positive atmospheric flux. A negative flux refers to the ocean absorbing carbon dioxide. Think of these fluxes as an inhale and an exhale, where the net effect of these opposing directions determines the overall effect.

Colder and nutrient rich [parts of the ocean are able to absorb more carbon dioxide](#) than warmer parts. Therefore, the polar regions typically serve as carbon sinks. By 2100, most of the global ocean is expected to be made up of carbon dioxide, potentially altering the ocean chemistry and lowering the pH of the water, making it more acidic.

Biological Carbon Found in Soil



Carbon is sequestered in soil by plants through photosynthesis and can be stored as soil organic carbon (SOC). Agroecosystems can degrade and deplete the SOC levels but this carbon deficit opens up the opportunity to store carbon through new land management practices. Soil can also store carbon as carbonates. Such carbonates are created over thousands of years when carbon dioxide dissolves in water and percolates the soil, combining with calcium and magnesium minerals, forming “caliche” in desert and arid soil.

Carbonates are inorganic and have the ability to store carbon for more than 70,000 years, while soil organic matter typically stores carbon for several decades. Scientists are working on ways to accelerate the carbonate forming process by adding finely crushed silicates to the soil in order to store carbon for longer periods of time.

Biological Carbon Found in Forests



About 25 percent of global carbon emissions are captured by plant rich landscapes such as forests, grasslands and rangelands. When leaves and branches fall off plants or when plants die, the carbon stored either releases into the atmosphere or is transferred into the soil. Wildfires and human activities like deforestation can contribute to the diminishment of forests as a carbon sink.

Biological Carbon Found in Grasslands

While forests are commonly credited as important carbon sinks, California's majestic green giants are serving more as carbon sources due to rising temperatures and impact of drought and wildfires in recent years. Grasslands and rangelands are more reliable than forests in modern-day California mainly because they don't get hit as hard as forests by droughts and wildfires, according to research from the University of California, Davis. Unlike trees, grasslands sequester most of their carbon underground. When they burn, the carbon stays fixed in the roots and soil instead of in leaves and woody biomass. Forests have the ability to store more carbon, but in unstable conditions due to climate change, grasslands stand more resilient.

Geological

Geological carbon sequestration is the process of storing carbon dioxide in underground geologic formations, or rocks. Typically, carbon dioxide is captured from an industrial source, such as steel or cement production, or an energy-related source, such as a power plant or natural gas processing facility and injected into porous rocks for long-term storage.

Carbon capture and storage can allow the use of fossil fuels until another energy source is introduced on a large scale.

Technological

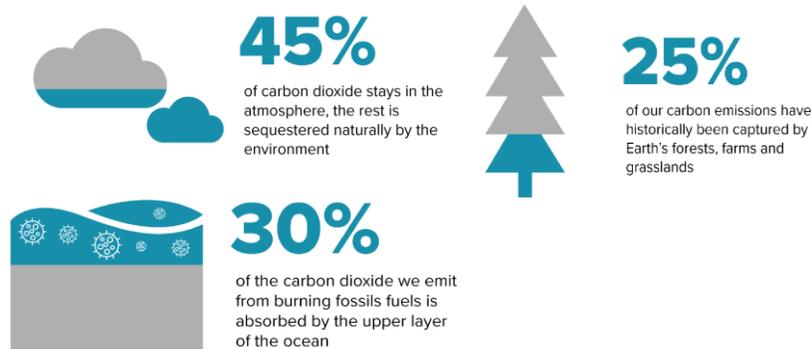
Scientists are exploring new ways to remove and store carbon from the atmosphere using innovative technologies. Researchers are also starting to look beyond removal of carbon dioxide and are now looking at more ways it can be used as a resource.

Graphene production: The use of carbon dioxide as a raw material to produce graphene, a technological material. Graphene is used to create screens for smart phones and other tech devices. Graphene production is limited to specific industries but is an example of how carbon dioxide can be used as a resource and a solution in reducing emissions from the atmosphere.

Direct air capture (DAC): A means by which to [capture carbon directly from the air using advanced technology plants](#). However, this process is energy intensive and expensive, ranging from \$500-\$800 per ton of carbon removed. While the techniques such as direct air capture can be effective, they are still too costly to implement on a mass scale.

Engineered molecules: Scientists are engineering molecules that can change shape by creating new kinds of compounds capable of singling out and capturing carbon dioxide from the air. The engineered molecules act as a filter, only attracting the element it was engineered to seek.

Sequestration Facts



The Future of Carbon Sequestration

Scientists are exploring [new ways to remove and store carbon](#) from the atmosphere using innovative technologies. Researchers are also starting to look beyond removal of carbon dioxide and are now looking at more ways it can be used as a resource.

Graphene production: The use of carbon dioxide as a raw material to produce graphene, a technological material. Graphene is used to create screens for smart phones and other tech devices. Graphene production is limited to specific industries but is an example of how carbon dioxide can be used as a resource and a solution in reducing emissions from the atmosphere.

Impacts of Carbon Sequestration

- About 25% of our carbon emissions have historically been captured by [Earth's forests, farms and grasslands](#). Scientists and land managers are working to keep landscapes vegetated and soil hydrated for plants to grow and sequester carbon.
- As much as 30% of the carbon dioxide we emit from burning fossils fuels is absorbed by the upper layer of the ocean. But this raises the water's acidity, and [ocean acidification](#) makes it harder for marine animals to build their shells. Scientists and the fishing industry are taking proactive steps to monitor the changes from carbon sequestration and adapt fishing practices.



**A Profile of the
NATURAL
RESOURCES SECTOR
IN NEW BRUNSWICK**

September 2021

NBjobs.ca

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Note: This profile includes data from a variety of sources that use different methodologies and are subject to periodic retroactive revisions. As a result, data from one source may not match with data from other datasets. Information about the sources and methodologies used are available upon request. In some instances source data points have been suppressed. Where this occurs, the data values presented have been inferred from non-suppressed data. Also, some totals may not equal the sum of their components due to rounding.

Sector Definition

For the purpose of this profile, the Natural Resources sector includes the following sectors:

Agriculture, Forestry, Fishing and Hunting: This sector consists of establishments that are primarily engaged in growing crops, raising animals, harvesting timber, harvesting fish and other animals from their natural habitats and providing related support activities. Establishments primarily engaged in agricultural research or that supply veterinary services are not included in this sector.

Mining, Quarrying, and Oil & Gas Extraction: This sector consists of establishments that are primarily engaged in exploration for and/or extracting naturally occurring minerals. These can be solids, such as coal and ores; liquids, such as crude petroleum; and gases, such as natural gas.

The scope of this profile includes North American Industry Classification System (NAICS 2017) sectors 11 and 21.

Legend

 Natural Resources sector	 New Brunswick
 All sectors	 Canada
 Male	 Female

Current Business Environment

GDP* and Productivity

In 2019:

- The Natural Resources sector represented 4.5% of New Brunswick's (NB) GDP, contributing \$1.3 billion (chained 2012 dollars)^{1, 2}
- NB Labour Productivity^{2, 3} (a measure of productivity based on GDP per hour worked in the sector):
 - This sector – \$49.07 output per hour of work (chained 2012 dollars)
 - Average of all sectors – \$48.47 output per hour of work (chained 2012 dollars)

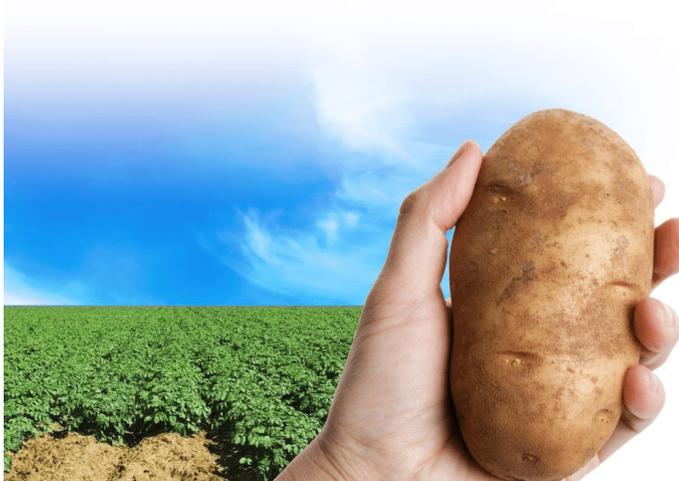
* Gross Domestic Product

Proportion of GDP in NB: 2019¹
Natural Resources Sector

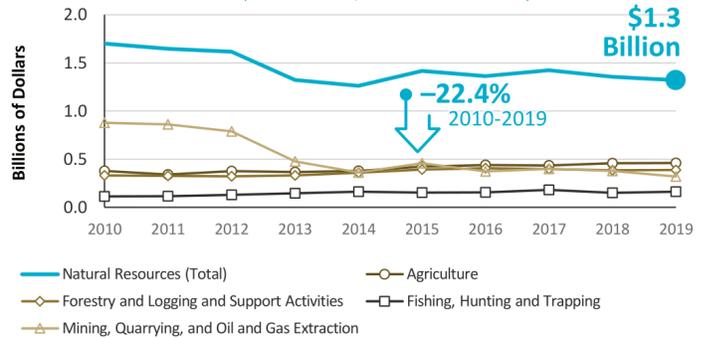
Natural Resources
4.5%



All other sectors
95.5%



Real GDP²
NB Natural Resources Sector
(at Basic Prices, Chained 2012 Dollars)

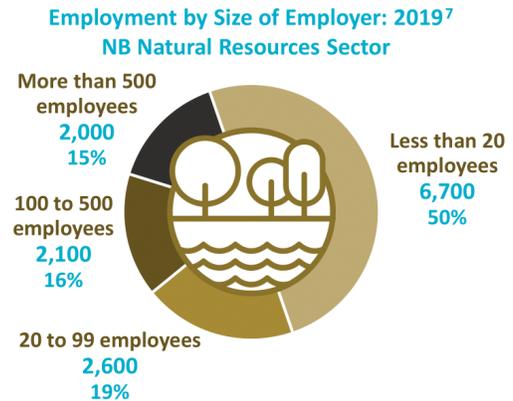
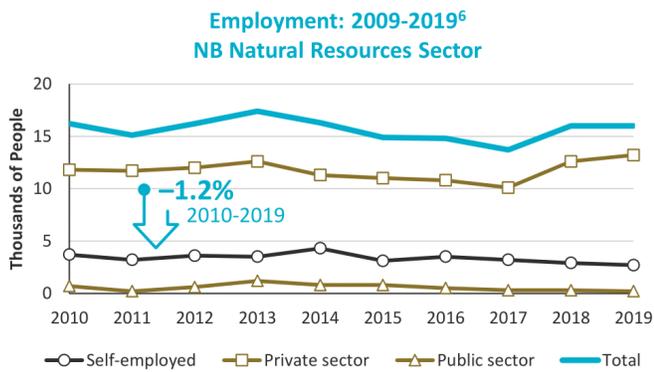


Employment in New Brunswick

In 2019:

- 16,000 were employed in the NB Natural Resources sector⁴
- 4.4% of all employed in NB worked in this sector⁴
- 7.5% of employees in this NB sector were part of a union and/or covered by a collective agreement – versus 29.1% of all employees in the Province⁵

Employment: 2019 ⁴ NB Natural Resources Sector					
Sector	Employed	% Change from 2010	Full Time	Part Time	Unemployed (Unemployment Rate)
All sectors (Total)	361,100	+1.0%	85.0%	15.0%	31,900 (8.1%)
Natural Resources (Total)	16,000	-1.2%	93.8%	6.3%	3,100 (16.2%)
Agriculture	5,800	-3.3%	86.2%	13.8%	1,100 (15.9%)
Forestry and Logging and Support Activities	3,600	-2.7%	97.2%	2.8%	500 (11.9%)
Fishing, Hunting and Trapping	2,400	+33.3%	95.8%	4.2%	900 (28.1%)
Mining, Quarrying, and Oil and Gas Extraction	4,200	-12.5%	100.0%	0.0%	600 (12.5%)



Human Resources Profile

Demographics

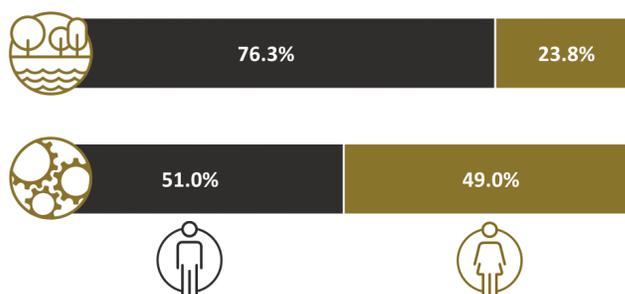
In 2019:

- 19,100 people were part of the labour force in the NB Natural Resources sector, of which 16,000 were employed⁴

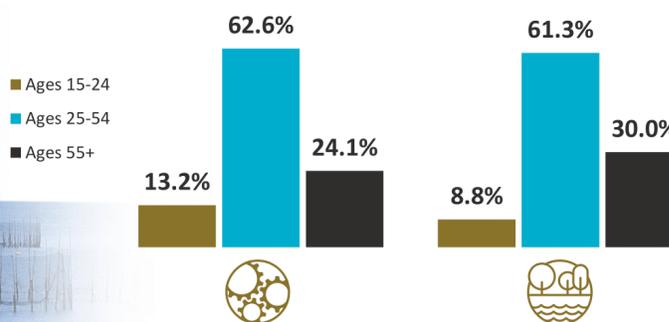
From 2010 to 2019:

- The percentage of females employed in the sector increased from 21.0% to 23.8%⁴
- The percentage of workers employed in this sector:⁴
 - Ages 15-24 decreased 1.1 percentage points
 - Ages 25-54 decreased 4.8 percentage points
 - Ages 55 and over increased 5.9 percentage points

NB Employment by Sex: 2019⁴
Natural Resources Sector vs All Sectors



NB Employment by Age: 2019⁴
Natural Resources Sector vs All Sectors



Major Occupations

In 2019:

- 33.2% of those working in the NB Natural Resources sector worked in one of the five National Occupation Code (NOC) occupations listed in the table to the right⁸
- These 4,300 employees represented 1.2% of all employed in NB⁸

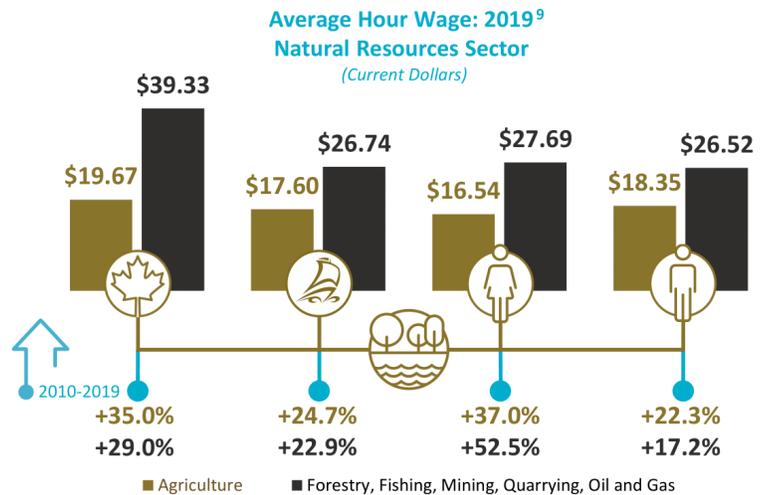


Major Occupations: 2019 ⁸ NB Natural Resources Sector		
Occupation	Employed	NOC
General farm workers	1,500	8431
Managers in agriculture	1,200	0821
Fishermen/women	900	8262
Logging and forestry labourers	400	8616
Transport truck drivers	400	7511

Wage and Salary Information

In 2019:

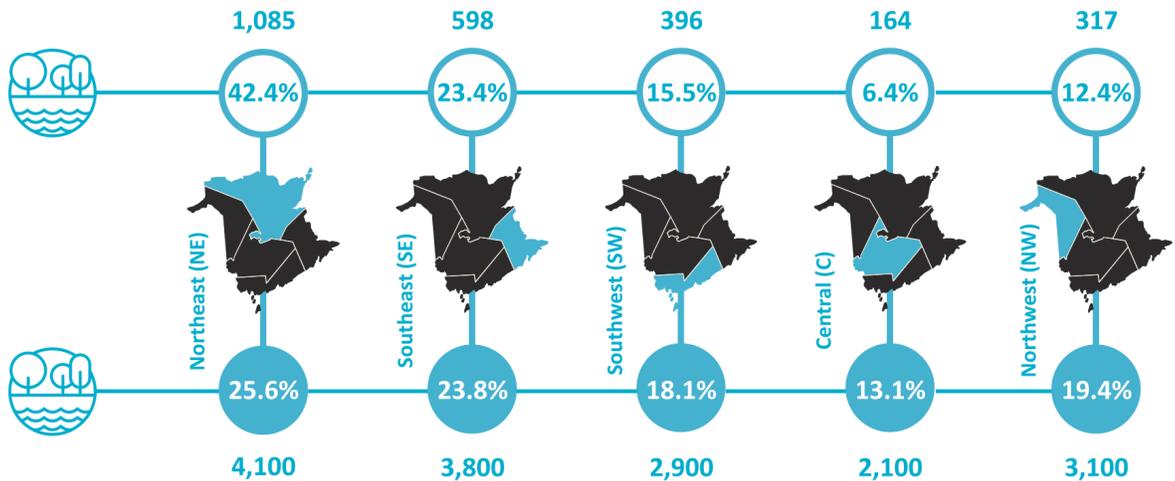
- The average wage in the NB Agriculture sector (\$17.60) was less than than the average NB wage across all sectors (\$23.49)⁹
- The average wage in the NB Forestry, Fishing, Mining, Quarrying, Oil and Gas sector (\$26.74) was greater than than the average NB wage across all sectors (\$23.49)⁹



Regional Highlights

Employers

Regional Distribution: 2019¹⁰

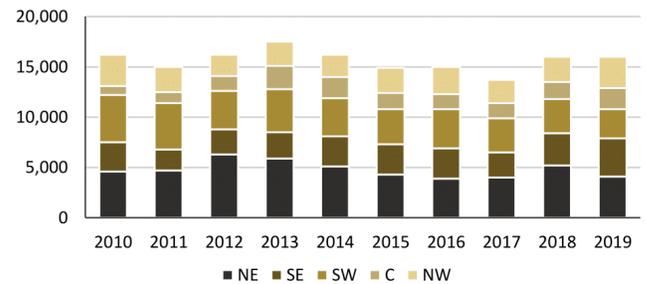


Employed

Regional Distribution: 2019¹¹

Number of Regional Employers by Employment Size: 2019 ¹⁰ NB Natural Resources Sector					
Region	1-9	10-49	50-199	200+	Total
NE	1,007	70	8	0	1,085
SE	561	33	3	1	598
SW	343	48	1	4	396
C	140	22	2	0	164
NW	231	79	6	1	317
Unknown	30	7	0	0	37
TOTAL	2,312	259	20	6	2,597

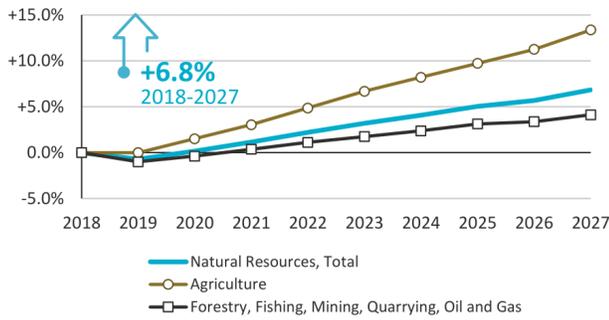
Employment by Economic Region: 2010-2019¹¹
NB Natural Resources Sector



Business Outlook 2018-2027

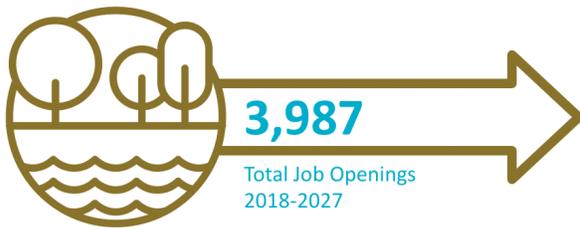
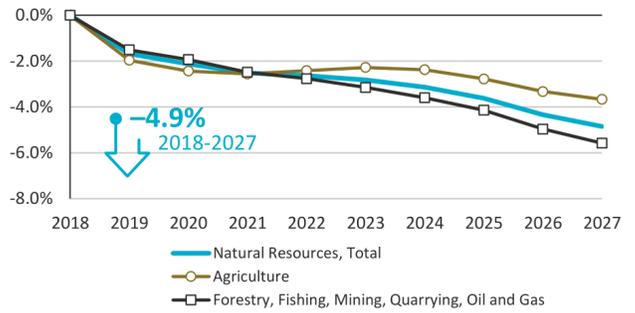
GDP Forecast

**Forecasted Change in Real GDP⁸
NB Natural Resources Sector**
(Relative to 2018)

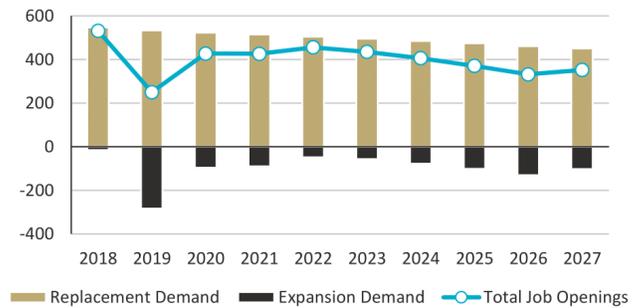


Employment Forecast

**Forecasted Change in Employment⁸
NB Natural Resources Sector**
(Relative to 2018)



**Forecasted Job Openings⁸
NB Natural Resources Sector**



Links for Further Information

Government Sources

- NBjobs.ca
- Labour Market Information
- Sector Definitions - North American Industry Classification System, 2017 (NAICS)
- Classification of Occupations - National Occupational Classification, 2016 (NOC)

Sector Associations

- Association of Registered Professional Foresters in New Brunswick
- Canada Beef
- Canadian Institute of Forestry
- Canadian Institute of Mining
- G3 Canada
- Grand Manan Fishermen's Association
- Maritime College of Forest Technology
- Mining Association of Canada

For Additional Information Contact:

New Brunswick Department of Post-Secondary Education,
Training and Labour

Imi@gnb.ca

Prepared by:



Data Sources

- ¹ Statistics Canada, Table 36-10-0400
- ² Statistics Canada, Table 36-10-0402
- ³ Statistics Canada, Table 36-10-0489
- ⁴ Statistics Canada, Table 14-10-0023
- ⁵ Statistics Canada, Table 14-10-0070
- ⁶ Statistics Canada, Table 14-10-0027

- ⁷ Statistics Canada, Table 14-10-0068
- ⁸ Stokes Economics, Customized New Brunswick Forecast
- ⁹ Statistics Canada, Table 14-10-0064
- ¹⁰ Statistics Canada via the Community Data Program
- ¹¹ Statistics Canada, Table 14-10-0392



CHAPTER 1

Atlantic
Provinces

REGIONAL PERSPECTIVES REPORT



Government of Canada
Gouvernement du Canada

Canada

1.1 Introduction

Atlantic Canada comprises the provinces of New Brunswick (N.B.), Nova Scotia (N.S.) and Prince Edward Island (P.E.I.) (collectively referred to as the Maritimes), as well as Newfoundland and Labrador (N.L.). Situated on the east coast of the country, Atlantic Canada spans three different climate regions that include cool humid-continental, sub-Arctic and Arctic tundra (Vasseur and Catto, 2008) and consists of regions and communities that differ in many ways, including population densities, natural resources, key industries and cultures. With approximately 42,000 km of coastline (Lemmen and Warren, 2016), Atlantic Canada is characterized by diverse coastal systems including sandy beaches, estuaries, intertidal flats, salt marshes, cobble beaches, cliffs, bluffs, rock shores and more (van Proosdij et al., 2016). This chapter does not include Nunatsiavut in Newfoundland and Labrador, as this region is discussed in the Northern Canada chapter.

1.1.2 Economy

Key industries in Atlantic Canada include agriculture, fisheries and aquaculture, forestry, tourism, marine transportation, shipbuilding, information technology, mining, oil and gas, renewable energy, manufacturing, aerospace and bioscience (Nova Scotia Business Inc., 2020; Government of Newfoundland and Labrador, 2017; Government of Prince Edward Island, 2016). Some of these sectors may experience new opportunities from climate change—for example, higher temperatures can lead to longer tourism and growing seasons. Negative climate change impacts, however, are expected to predominate, particularly in sectors that are sensitive to projected changes in climate due to their reliance on natural resources and marine and coastal infrastructure, such as fisheries, aquaculture, agriculture, forestry, transportation and offshore oil and gas (Vasseur and Catto, 2008)

1.5 Forestry, agriculture and fisheries are vulnerable to climate change

Atlantic Canada's natural resource industries are vulnerable to the impacts of climate change. While examples of adaptation are found in each sector—forestry, agriculture, fisheries and aquaculture—**there remains a lack of collaboration amongst stakeholders to reduce risks from climate change.**

Foresters, farmers and fishers are interested in understanding the projected climate changes in the short, medium, and long terms to improve their planning and decision making. The challenges presented by climate change for Atlantic Canada's natural resource industries are numerous, but also divergent among the different resource sectors of forestry, agriculture, fisheries and others.

1.5.1 Introduction

Atlantic Canada's natural resource industries play a crucial role for the region's economies, and are vulnerable to the impacts of climate change. The forestry, agriculture and fisheries sectors

have made progress on adaptation, and benefited from collaborations between multiple levels of government, practitioners and communities (e.g., Nova Scotia Federation of Agriculture, 2020; Halofsky et al., 2018; Steenberg et al., 2011). Natural resource industries are also considering potential opportunities (e.g., longer growing season, harvesting of newly arrived species), in parallel with negative impacts (e.g., invasive species). A commonality amongst the various natural resource sectors is a strong need for research, monitoring and education, as well as a need for increased progress on action. Rigorous monitoring programs are central to climate change adaptation across all sectors in order to reduce uncertainty and inform the development of new policies and regulations.

1.5.2 Forests

The changing climate will have significant impacts on Atlantic Canada's forests (see Figure 1.15; Taylor et al., 2017), with implications for the forest sector, as well as natural areas, including urban forests. Short-term concerns include increases in natural disturbances, such as storm events and pest outbreaks, increased fire risks and invasions by non-native species (MacLean et al., 2021; Taylor et al., 2020). In the longer term, warmer temperatures will lead to shifts in the ranges of tree species. As important species in the region (such as Red Spruce, Black Spruce and Balsam Fir) are projected to decline in growth or abundance (Steenberg et al., 2013a), there will be significant socioeconomic impacts in the forest sector and in forest-dependent communities, including many Indigenous communities. Without action, these impacts could lead to a reduction in timber supply, employment, traditional Indigenous wood products, recreation, aesthetics and other ecosystem services (Ochuodho et al., 2012; see also Ecosystem Services chapter of the National Issues Report). Proactively adapting to these changes helps protect against losses, and also has the potential to generate benefits through new and enhanced wood products and services (Halofsky et al., 2018; Steenberg et al., 2011).

Planned and proactive adaptation is important for the forest sector, in part because of the long time horizons of the sector. Adaptation to date has focused primarily on research and planning to integrate the effects of climate change on forest ecosystem dynamics into modelling used for planning and policy development.



Figure 1.15: Managed Acadian forests in Nova Scotia. Photo courtesy of Jane Kent, Nova Scotia Department of Lands and Forestry.

Regional integrated assessments have emerged as a key planning tool for Atlantic Canada's forestry sector. The Maritime Regional Integrated Assessment (MaRIA), which began in 2017, involves provincial governments and forestry industries working together to assess forest vulnerability and integrate climate change considerations into forest management planning frameworks, with an emphasis on forest modelling tools (Taylor, 2021). As part of MaRIA, in New Brunswick, growth and yield curves that were developed using climate change scenarios are being used to project future wood supply (Steenberg, 2021). Additionally, a climate-change-dependent forest succession model will be developed that can be used in the provincial forest planning model to predict the forest regeneration response after harvests. The outcomes support the integration of climate change into the provincial five-year forest management planning cycle. Nova Scotia is similarly developing new protocols to integrate both forest carbon and climate change impacts into its strategic and landscape-level forest modelling and management planning (Steenberg, 2020), while Newfoundland and Labrador has supported similar research (Searls et al., 2021). More recently, the Nova Scotia Department of Lands and Forestry, in collaboration with Nova Scotia Environment and Climate Change, initiated the Climate Adaptation Leadership Program (CALP). The purpose of this program is to develop a climate change adaptation strategy for the province's Department of Lands and Forestry, with funding from the Province and from Natural Resources Canada through the Building Regional Adaptation Capacity and Expertise (BRACE) program (Natural Resources Canada, 2021).

Other examples of forest management adaptation include intermediate silviculture treatments, like precommercial thinning to favour species expected to flourish through a changing climate

(Thiffault et al., 2021) and adjusting urban forest management to reflect climate change impacts (see Case Story 1.10). Assisted species migration and diversification offer yet another approach to adaptation being used in the forestry sector, which includes provenance trials, the planting of genetically improved seedlings, and restoration silviculture (Halofsky et al., 2018).

Case Story 1.10: Halifax's Urban Forest Master Plan

A healthy and vibrant urban forest can alleviate some climate change impacts—such as urban heat islands and increased stormwater runoff—by directly shading buildings and infrastructure, lowering ambient

temperature, removing water from the soil, and slowing stormwater flow and decreasing runoff (Duinker et al., 2015; see also the Ecosystems Services and Cities and Towns chapters of the National Issues Report). A desire to maximize these and other beneficial ecosystem services in Halifax has led to many improvements in the urban forest management.

Halifax Regional Municipality's urban forester and municipal planners worked with Dalhousie University researchers to develop the city's first Urban Forest Master Plan (UFMP), which was adopted by Regional Council in 2012. Using adaptive management to address the uncertainty of climate change is a core principle of the UFMP (Steenberg et al., 2013b). The UFMP prescribes an increased rate of tree planting to ensure that this outpaces tree mortality, and also recommends a transition from reactive tree maintenance to a proactive pruning program. Since 2013, over 8,800 trees have been planted on municipal property, an initiative that can be directly attributed to the UFMP (Foster and Duinker, 2017; Steenberg et al., 2013b). Planting prescriptions included measures to increase species diversity and build resilience to climate change. The cyclical pruning program is intended to promote tree health and to prevent conflicts with infrastructure, ensuring a healthier urban tree canopy.

The Halifax experience of urban forest management highlights the importance of partnerships between researchers, municipal staff, and citizens, from the time of inception of a project. Public consultations informed the UFMP, and it was clear from these that most people want more trees in the city. This support allowed the municipality to increase spending on the urban forest, which is an important contributor to increasing climate resilience.

1.5.3 Agriculture

The net impact of climate change on agriculture in Atlantic Canada will be determined by the balance between opportunities and challenges (Ochuodho and Lantz, 2015). In a project called AgriRisk (Nova Scotia Federation of Agriculture, 2020), the opportunities identified included an extended growing season and the ability to grow higher-value crops, while the challenges included the risks associated with a greater frequency of extreme events, damage to crops and/or infrastructure, uncertainty in global markets, and potential changes in pest spectrum and

incidence of disease. In Nova Scotia, a diverse group of researchers through the Nova Scotia Federation of Agriculture (NSFA) carried out a risk assessment focused on the wine grape industry. The goal was to “integrate and make use of the best available data sets and key variables associated with risks along the grape and wine value chain to help contribute to achieving the outcome of a risk-aware grape and wine industry.” The project developed models and interactive climate tools to help users explore current and future climate conditions in the province (Nova Scotia Federation of Agriculture, 2020).

For agriculture, adaptation approaches at the farm level (see Figure 1.16) have focused mainly on reducing non-climatic stressors through management practices. For example, farmers are planting cover crops, changing crop rotation and altering tillage practices to make the soil less vulnerable to erosion (Russell, 2018). Producer decisions are supported by the Alternative Land Use Services (ALUS) Program in Prince Edward Island (ALUS Canada, 2020). The program provides financial incentives to farmers for projects that support sustainable agriculture practices. For example, farmers are compensated for each acre of land used to create soil conservation structures like grassed waterways, terraces or berms. Other farm management adaptation options include flood control, shifting crop varieties, soil management, pest management, artificial cooling in livestock buildings (Arnold and Fenech, 2017; Wall and Smit, 2005), crop diversification and enhancing biodiversity for resilience (Wall and Smit, 2005);



Figure 1.16: Agriculture operations on Prince Edward Island. Photos courtesy of Don Jardine.

1.5.4 Fisheries

The vulnerability of fisheries to climate change is a major socioeconomic and ecological concern in Atlantic Canada, and the need for investment in adaptation has been well identified (Hutchings et al., 2012; Rice and Garcia, 2011). Many rural and coastal communities are highly dependent on fisheries. Given the scale and complexity of marine systems, climate change impacts are highly uncertain and potentially severe (see Sector Impacts and Adaptation chapter of the National Issues Report). Examples of important indicators of marine climate change include rising sea levels, increased ocean temperatures, hypoxia and acidification (Greenan et al., 2019), all of which affect marine ecosystems and fish stocks. Climate change can also increase sedimentation, which can result in fish habitat degradation and population declines

(Bernier et al., 2018). More extreme weather also presents technical and safety issues for fishery fleets (Rezaee et al., 2016). In 2017, a lack of available food for right whales in the Bay of Fundy may have contributed to their relocation into the Gulf of St. Lawrence, where the interaction of whales with fixed-gear fisheries led to a significant number of whale deaths, and resulted in the development of gear that is less detrimental to whales (Murison, 2017).

Changes to marine biodiversity present socioeconomic risks for those directly and indirectly connected to the fisheries sector (see Figure 1.17). For example, in the Outer Bay of Fundy, water temperatures have affected the hydrodynamics of ocean currents competing to enter the Bay of Fundy, resulting in an influx of warm Gulf Stream water (Drinkwater et al., 2003). This extreme change in temperature interacts with pH changes and more frequent heavy rainfall events, resulting in severe cumulative impacts on marine biodiversity (Bernier et al., 2018).

Impacts on fisheries infrastructure are another area of concern, with severe storm events placing a tremendous burden on the wharves that the fisheries depend on. Adaptation efforts in the fisheries sector on Grand Manan Island, New Brunswick, for instance, were informed by assessments of future needs under different climate change scenarios (Signer et al., 2014). Improvements to key fisheries infrastructure will help ensure that they can withstand future storm events.



Figure 1.17: Lobster fishing traps in the Gulf of St. Lawrence. Photos courtesy of Don Jardine.

1.5.5 Aquaculture

The marine stages of aquaculture production face a number of challenges related to climate change, including temperatures that approach or exceed the upper thermal limit of species, low water oxygen levels (hypoxia), acidification, more frequent and severe storms, and algal blooms (Reid et al., 2019a, b).

The primary finfish reared in the Atlantic region is the Atlantic salmon (*Salmo salar*), and several academic/ industry research partnerships are addressing challenges from climate change to help the industry to adapt over the next few decades. These include the following: Modules J and K of the Ocean Frontier Institute (“Improving Sustainability and Mitigating the Challenges of Aquaculture” and “Novel Sensors for Fish Health and Welfare,” respectively), the “Mitigating the Impact of Climate-Related Challenges on Atlantic Salmon Aquaculture (MICCSA)” project, the “Addressing the Challenges Faced by Atlantic Salmon at Cold Temperatures” project, and the

newly funded Atlantic Salmon Gill Health initiative. The “Mitigating the Impact of Climate-Related Challenges on Atlantic Salmon Aquaculture” (MICCSA) project involves several universities, the Huntsman Marine Science Centre, and industry partners including the Centre for Aquaculture Technology Canada, Somru Biosciences and AquaBounty, Canada. To date, this large project has defined the upper thermal tolerance of Atlantic salmon of the Saint John River stock (Gamperl et al., 2020; Leeuwis et al., 2019), examined the effects of elevated temperature and hypoxia on salmon production (Gamperl et al., 2020), examined pathogen-host interactions as affected by temperature (Zanuzzo et al., 2020), and directly measured Atlantic salmon behavior, distribution and physiology during summer sea-cage conditions (Gamperl et al., 2021). Further, the MICCSA research team is currently working on identifying genetic markers that will allow for the selection of broodstock with enhanced resistance to disease, sea lice and temperature (Beemelmanns et al. 2021a, b and 2020). The Ocean Frontier Institute has also funded projects at Memorial University (Model J.2) and Dalhousie University (Module K) that are advancing knowledge of how salmon and their populations are affected by adverse environmental conditions (Zanuzzo, 2022; Gerber et al., 2021, 2020; Stockwell et al., 2021). The industry is also exploring technological improvements to increase the depths of their sea cages, in compliance with ISO standards (International Organization for Standardization, 2015) to help ensure that these structures can withstand major storms, which are increasing in intensity as a result of climate change.

The primary molluscan aquaculture species in Atlantic Canada are blue mussels and Eastern oysters, which comprise approximately 35% of all Atlantic Canadian farmed organisms (Statistics Canada, 2021). The impacts of climate change on primary and secondary production have been investigated since the 1990s, and the general consensus is that infrastructure, primary productivity, seed supply, feeding physiology and carrying capacity are changing rapidly in Atlantic Canada and in many coastal regions (e.g., Reid et al. 2019a, b; Foster et al., in preparation). There has been an increase in disease and pest prevalence, an extension of the range of predators, and increasing challenges related to invasive organisms (Best et al., 2017, 2014; Lowen et al., 2016). Recent research has indicated that ocean acidification is affecting natural food supply dynamics, thereby affecting shellfish productivity at the larval and post-larval stages (Kong et al., 2019; Clements et al., 2018; Clements and Hunt, 2017; Clements and Chopin, 2016).

In the aquaculture sector, ocean dynamics, ice cover and changes in seasonal patterns of food supply are being addressed through the adoption of newer green technology by producers, and by using equipment that is storm resistant, well-engineered, better sited, and better suited to withstand the changing coastal conditions in summer and winter (International Organization for Standardization, 2020; Government of Newfoundland and Labrador, 2019). Hatchery production of the main cultivated mollusks (oysters, mussels) has been developed as a risk mitigation measure against spurious natural seed supplies and as a way of selecting strains that will perform better under changing conditions. For instance, three molluscan shellfish hatcheries have been constructed since 2018 in Atlantic Canada—two oyster hatcheries (Bideford Shellfish Hatchery, Prince Edward Island, and Maison BeauSoleil Oyster Hatchery in Neguac, New Brunswick), and one mussel hatchery and nursery in Borden, Prince Edward Island. Atlantic Canadian shellfish hatcheries are being employed to reduce dependence on variable natural

seed recruitment by producing a more reliable seed source that can grow under the warming climate (Guo et al., 2009). Finally, the use of algae, mollusks and echinoderms in reducing both the impacts of marine finfish farming and climate change is beginning to come to the forefront in Atlantic Canada, across Canada and globally (Clements and Chopin, 2016).



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.
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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



FIGURE 1: Geographic extent of the East Coast region.

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).

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 inter-decadal 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 $0.90 \pm 0.37^\circ\text{C}$ (Figure 2a). Stations located along the Atlantic Ocean warmed $0.75 \pm 0.34^\circ\text{C}$ (Figure 2b), whereas those located along the Gulf of St. Lawrence coast warmed $1.12 \pm 0.43^\circ\text{C}$ (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 $+1.04^\circ\text{C}$ and $+0.89^\circ\text{C}$ 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 ($+0.38^\circ\text{C}/\text{decade}$) observed for the Labrador Sea during the period 1981–2010 (Han et al., 2013).

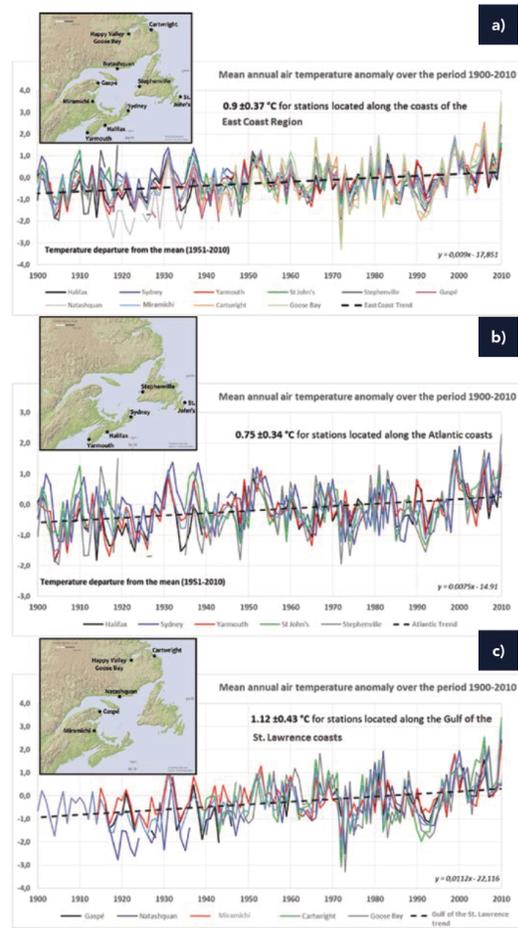


FIGURE 2: Mean annual air temperature anomaly (departure from the 1951–2010 mean) at **a)** meteorological stations in the East Coast region as a whole, **b)** stations located along the Atlantic Ocean, and **c)** stations located along the Gulf of St. Lawrence coast. The confidence interval is 95% for 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	1.4 to 2.2°C	2.5 to 3.8°C	3.4 to 5.0°C
	Precipitation	2.8 to 9.7%	6.5 to 15.4%	12.6 to 22.9%
Spring	Temperature	0.8 to 1.5°C	1.6 to 2.7°C	2.2 to 4.1°C
	Precipitation	0.3 to 8.1%	3.1 to 11.5%	8.8 to 18.5%
Summer	Temperature	0.9 to 1.6°C	1.7 to 2.7°C	2.2 to 3.8°C
	Precipitation	-1.9 to 5.2%	-1.4 to 5.7%	-4.0 to 7.1%
Autumn	Temperature	1.1 to 1.6°C	1.9 to 2.8°C	2.3 to 4.1°C
	Precipitation	-2.8 to 3.6%	-2.0 to 7.1%	-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).

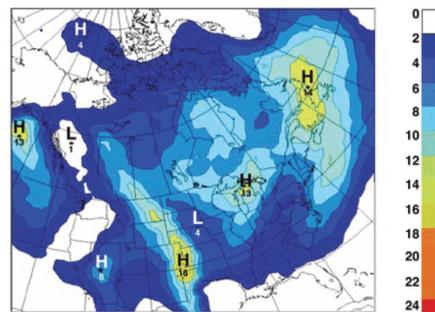


FIGURE 3: Spatial distribution of the annual average density of storm tracks for the 1961–2000 time period from ERA-40 reanalysis (a reanalysis of the global atmosphere and surface conditions for a period of 45 years, extending from September 1957 through August 2002, by the European Centre for Medium-Range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

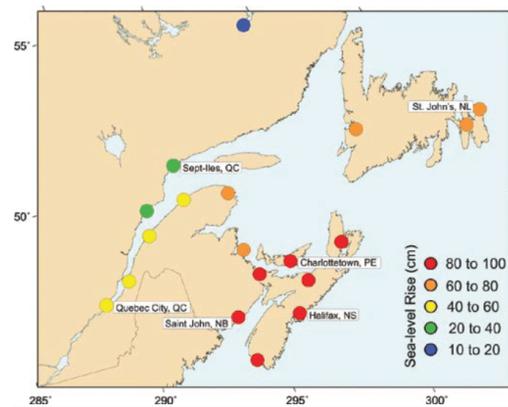


FIGURE 4: Projections of relative sea-level rise by the year 2100 for the median value of the high-emissions scenario (RCP8.5; after James et al., 2014). See Chapter 2 for additional information on sea-level projections. Sea-level projections through the 21st century are given in Figure 5 for the six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

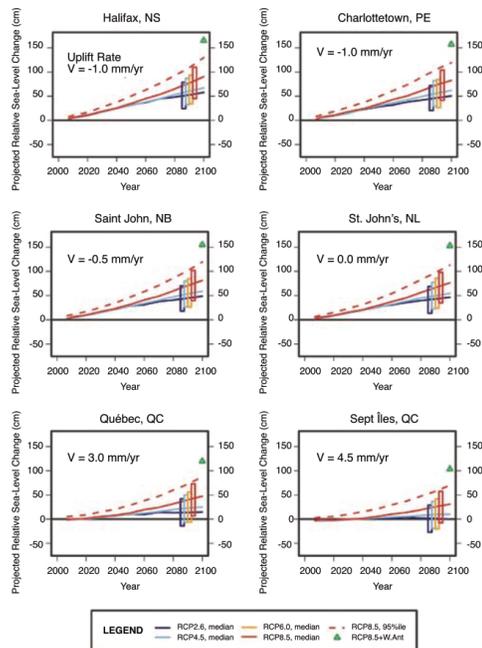


FIGURE 5: Projected sea-level change through the 21st century for selected communities in the East Coast region (after James et al., 2014, 2015). RCP2.6 is a low-emissions scenario, RCP4.5 and 6.0 are intermediate-emissions scenarios and RCP8.5 is a high-emissions scenario. The projected value at 2100 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).

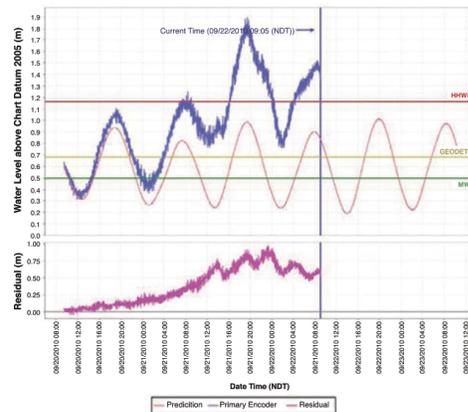


FIGURE 6: Example of surge caused by Hurricane Igor (October 2010) over several high-tide cycles in St. John's, NL. The higher high water large tide (HHWLT) was exceeded on at least three occasions (Canadian Hydrographic Service, Atlantic Region). Abbreviations: MWL, mean water level; NDT, Newfoundland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

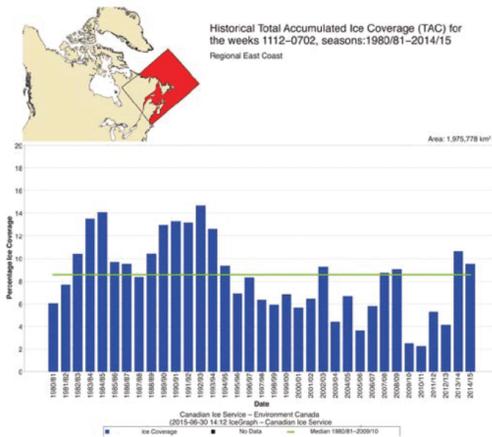


FIGURE 7: Historical total accumulated ice coverage for the weeks December 11 to February 7 from 1980 to 2015 in the East Coast region (Environment Canada, 2015).

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 Frobél, 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 Frobél, 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 forma-

tion 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 (*Ascidella 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

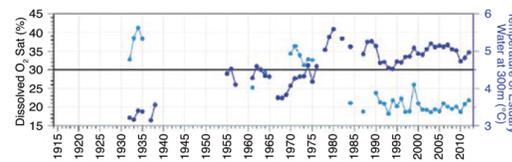


FIGURE 8: Dissolved oxygen saturation (O₂ Sat; light blue dots) and temperature (T; dark blue dots) between 295 m and the bottom in the deep central basin of the St. Lawrence estuary; 30% saturation marks the threshold of hypoxic conditions (DFO, 2010).

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: <ul style="list-style-type: none"> 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,

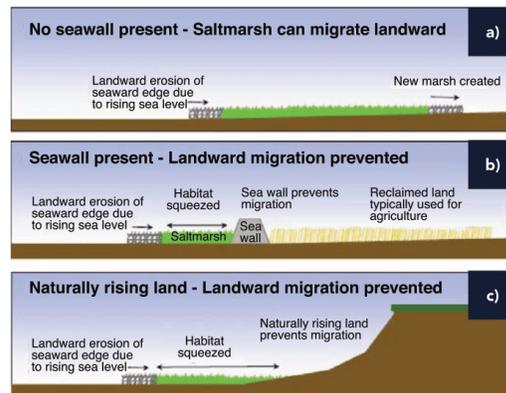


FIGURE 10: Illustration of the landward migration and prevented landward migration of coastal habitat that has been eroded by rising sea level: **a)** landward migration occurs naturally, **b)** migration has been prevented by a sea wall resulting in the 'squeeze' of habitat, and **c)** migration has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

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).

4.9 IMPACTS OF HUMAN ALTERATIONS ON THE COAST

Human activities leading to changes in land use, water-courses 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.

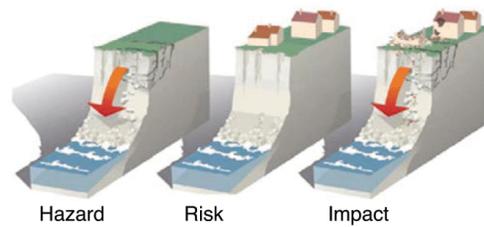


FIGURE 11: Coastal hazards, risks associated with exposure of valued assets (including ecosystem services) and impacts (adapted from Ministère de l'Écologie et du Développement durable de France, 2004).

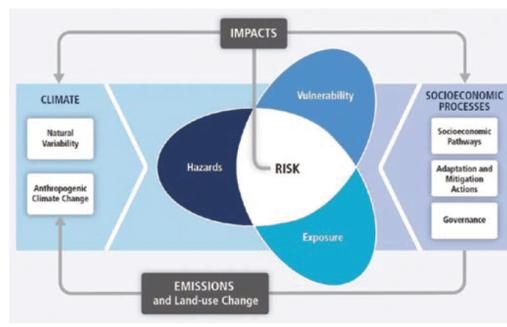


FIGURE 12: Climate impacts associated with coastal risks result from the interaction of coastal hazards and the vulnerability of exposed systems (from IPCC, 2014).

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 suêtes' 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

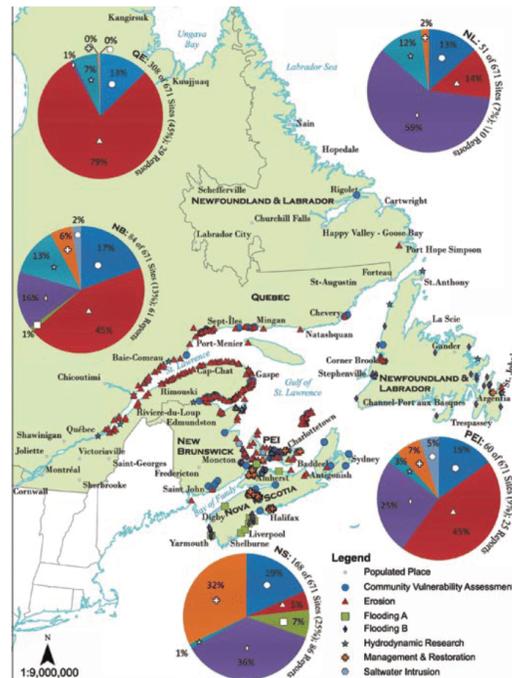


FIGURE 13: Spatial compendium of sites examined through vulnerability studies in the East Coast region. Legend categories include community vulnerability assessments, erosion (rate, shoreline adjustment, geological studies), flooding A (general extent with SLR), flooding B (SLR and/or storm surge with 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. Maclsaac and cartography by B. Perrott (Maritime Provinces Spatial Analysis Research Centre, Saint Mary's University).

Philip, NS; Webster et al., 2012b) and the effect of wave run-up (e.g., Halifax Harbour, NS; Xu and Perrie, 2012).

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 (Vasseur 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).

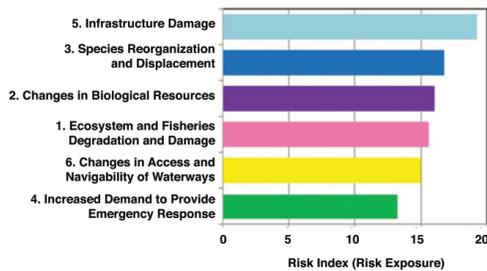


FIGURE 14: Index of climate change adaptation risks on the 50-year time scale for each of six risks identified by the Fisheries and Oceans Canada (DFO) with respect to their department operations. Risk evaluation was based on expert opinion of magnitude of impact (ranked from 0 to 5, where 5 is very 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	<ul style="list-style-type: none"> ▪ 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 	<ul style="list-style-type: none"> ▪ 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)	<ul style="list-style-type: none"> ▪ decreased flushing rates and food availability to shellfish ▪ changes in abundance of species used for food and fishmeal 	<ul style="list-style-type: none"> ▪ accumulation of wastes under nets ▪ increased operating costs
Sea-level rise	<ul style="list-style-type: none"> ▪ loss of areas for aquaculture ▪ loss of areas providing physical protection 	<ul style="list-style-type: none"> ▪ infrastructure damage ▪ change in aquaculture zoning ▪ increased insurance costs
Increased storm activity	<ul style="list-style-type: none"> ▪ larger waves ▪ higher storm surges ▪ salinity changes ▪ structural damage 	<ul style="list-style-type: none"> ▪ 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 (Muisé 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-Annes-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 archaeological sites. Although it would generally be preferable to leave portions of the archaeological 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 archaeological 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 archaeological 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 archaeological 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



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 archaeological 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.*

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.

Coastal erosion can also expose previously unknown archaeological 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 km²) 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,

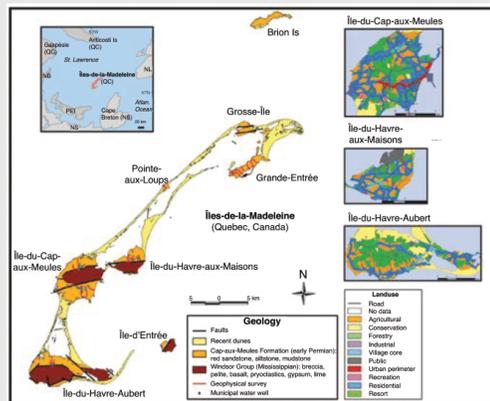


FIGURE 17: Location, geology and land use on the Îles de la Madeleine (Rémillard et al., 2012).

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).

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).

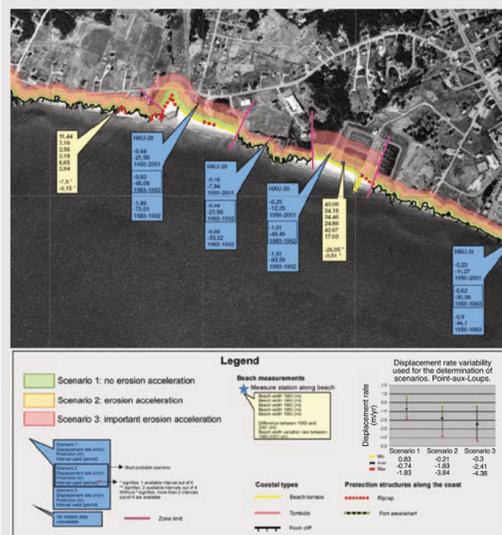


FIGURE 18: Example of digital-mapping scenarios and setbacks S1, S2 and S3 in Cap-aux-Meules, Îles de la Madeleine (adapted from Savard et al., 2008).

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 km² 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.

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

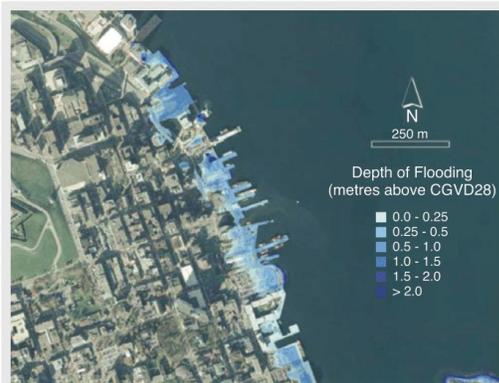


FIGURE 19: Flooding extent and depth (still-water) for a 57 cm sea-level rise with a once-in-50-years extreme-water-level event in downtown Halifax, derived using a light detection and ranging (LiDAR) digital elevation model displayed over a digital airphoto image (Forbes et al., 2009).

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.

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

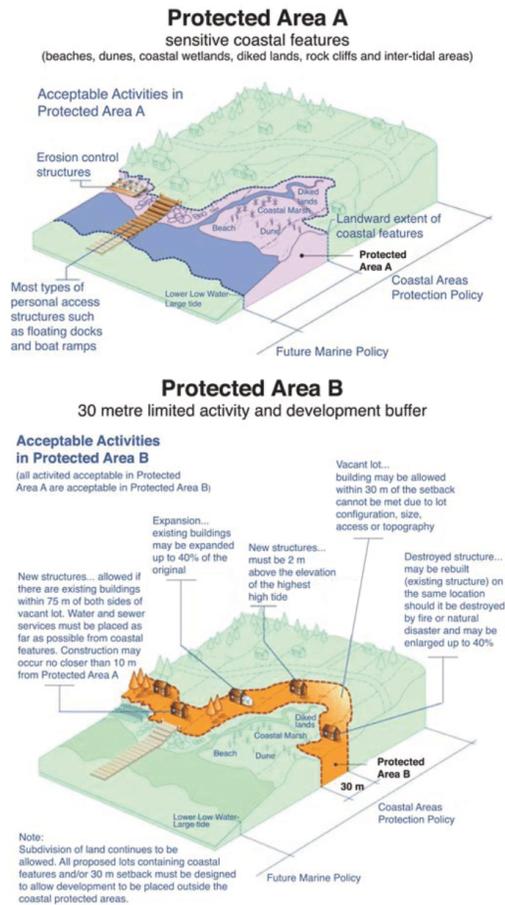


FIGURE 20: Zones A and B of the New Brunswick Coastal Areas Protection Policy (New Brunswick Department of Environment and Local Government, 2002).

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

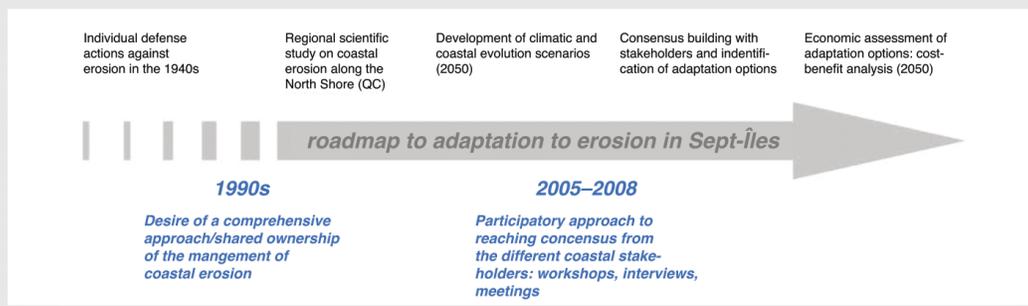


FIGURE 21: Main actions and interventions in the process leading to adaptation to erosion in Sept-Îles, QC.

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 km² 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. Similar trends have been observed for coastline armouring

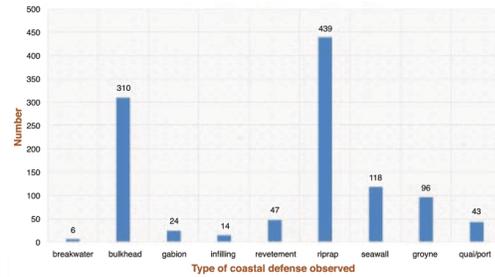


FIGURE 23: Inventory of coastal defence structures along the northern and eastern coasts of New Brunswick (Breau, 2000).

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 infre-

quently 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.

7 REFERENCES

- Abraham, J., Canavan, T. and Shaw, R., editors (1997): Climate variability and climate change in Atlantic Canada; Volume VI of Canada Country Study: Climate Impacts and Adaptation; Environment Canada, 130 p., <<http://publications.gc.ca/collections/Collection/En56-119-4-1997E.pdf>>.
- Adams, T. (2011): Climate change adaptation – groundwater management in Atlantic Canada; report prepared by the Newfoundland and Labrador Department of Environment and Conservation for Atlantic Climate Adaptation Solutions Association (ACASA), 9 p., <<http://atlanticadaptation.ca/sites/discoveryospace.upei.ca/acasa/files/Salt%20Water%20Intrusion%20Report.pdf>>.
- Allen, J.R.L. (2000): Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and southern North Sea coasts of Europe; *Quaternary Science Reviews*, v. 19, no. 12, p. 1155–1231.
- Allen, J.R.L. and Haslett, S.K. (2014): Salt-marsh evolution at Northwick and Aust warths, Severn Estuary, UK: a case of constrained autocyclicity; *Atlantic Geology*, v. 50, p. 1–17. doi:10.4138/atlgel.2014.001
- Amirault, J.F. and Gates, A.D. (1976): The storm of 2 February 1976 in the Maritime Provinces; Canada Department of Environment, Atmospheric Environment Service, Bedford, Nova Scotia, Report MAES7-76, 28 p.
- Arkema, K.K., Guannel, G., Verutes, G., Wood, S.A., Guerry, A., Ruckelshaus, M., Kareiva, P., Lacayo, M. and Silver, J.M. (2013): Coastal habitats shield people and property from sea-level rise and storms; *Nature Climate Change*, v. 3, p. 913–918, <<http://www.nature.com/nclimate/journal/v3/n10/abs/nclimate1944.html>>.
- Arlington Group Planning + Architecture Inc., Tetra Tech EBA, De Jardine Consulting and Sustainability Solutions Group (2013): Sea level rise adaptation primer: a toolkit to build adaptive capacity on Canada's south coasts; report prepared for BC Ministry of Environment, 149 p., <<http://www2.gov.bc.ca/gov/DownloadAsset?assetId=41DCF41B26B4449D8F54FAA0A8C751A9&filename=sir-primer.pdf>>.

Climate Change: Impacts on Forests



Government
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du Canada

Adaptation

How exactly is the climate forecast to change, and what could that mean for Canada's forests and forest management?

Canada is working to answer these questions in order to help the forest sector and society in general adapt to changing climate conditions. Today, forest managers must consider a range of possible future climates—those involving, for example, altered growing seasons, more insect infestations, more wildland fires and greater permafrost melting.

An important first step is to identify social, economic and environmental vulnerabilities to changing forest conditions. The next important step is to plan ways to reduce the impact of those vulnerabilities.

For example, projected increases in drought, fire, windstorms, and insect and disease outbreaks are expected to result in greater tree mortality. Fewer trees will reduce Canada's timber supply, which in turn will affect the economic competitiveness of Canada's forest industry. This would leave forestry-dependent communities vulnerable to job losses, closure of forestry processing facilities and an overall economic slump.

New thinking to deal with new conditions

Forest managers have traditionally assumed that the climate conditions of previous decades would be the conditions of future decades. Now, with more knowledge about climate and its patterns of change, forest managers are shifting their thinking.

Adaptation will mean taking action to minimize the negative effects of change. Yet at the same time some changes (such as longer growing seasons or moister weather patterns) may in fact offer new opportunities for the forest sector. Adaptation will therefore also be mean taking advantage of the positive impacts brought about by climate change.

The challenge of uncertainty

Many uncertainties exist about how, and to what extent, climate change will affect Canada's forests. This makes planning adaptation efforts a challenging exercise.

Dealing effectively with uncertainty requires having:

- the use of new tools and techniques for decision-making, such as scenario-planning exercises

- a good knowledge of the forest
- an understanding of risks
- the flexibility to adjust to changes

Risk management is a proven technique for identifying potential problems and then developing ways to: (1) reduce or avoid them; and (2) where they are unavoidable, respond to them to reduce negative outcomes.

In forestry, this means setting management objectives that recognize that the forests of the future will be different from those of today. By identifying the risks associated with these new conditions, forest planners and managers can then focus on finding ways to reduce or optimize the impact of those risks.

Support for adaptation from all parties

The Canadian Council of Forest Ministers (CCFM) has identified climate change adaptation as a priority for the forest sector. Many parties are working to support this priority:

- Forest scientists and forest practitioners across the country are assessing adaptation needs and adaptation options.
- The federal, provincial and territorial governments are collaborating in creating a range of products to help forest managers begin taking adaptation action.
- Provincial and territorial governments are developing approaches to addressing climate change, supporting climate research and raising awareness of the need for adaptation.
- Forest companies are beginning to address issues related to climate change in their management plans.

Practical tools aid adaptation strategies

Tools to analyze forest vulnerabilities

Forest scientists are developing a range of tools for assessing and managing climate-related risks and adaptation options. For example:

- Canadian Forest Service (CFS) researchers have developed a new software tool, BioSIM, which can predict stages in insect development during the growing season. BioSim has been used to predict how climate change might affect the risk of mountain pine beetle infestations in western Canada.
- CFS scientists have updated Canada's plant hardiness zones using recent climate data. The new map produced shows changes in the hardiness zones consistent with climate change.
- In partnership with provinces, the CFS is developing frameworks, guidebooks and tools to help forest management practitioners: better understand their readiness to adapt; and identify sources of vulnerability to sustainable forest management.

Tools to help forests and the forest sector adapt

Work is underway on several fronts to find ways to help forest stands adapt to new climatic conditions and disturbance regimes. For example:

- Researchers are looking at ways to reduce forests' vulnerability to fire and insect damage.
- Industry is exploring new markets for beetle-killed wood.
- Some forest companies have started using high-flotation tires to navigate wet areas, allowing them to extend their operating season.

Tools to inform forest management decision-making

Scientists are incorporating the data they have on changes in climate conditions into research and planning tools. This gives forest managers better information with which to make decisions. For example:

- Seedwhere is a geographic information system (GIS) tool that can guide planting and seeding decisions for forest regeneration. It can also help forest managers decide where to collect seeds and how far those seeds can be moved.

Looking to the long term

Forest managers need to include climate change considerations in long term planning if Canada is to maintain a competitive position in world markets. This means enhancing our ability to assess climate effects and identifying ways to adapt forests to ensure a healthy ecosystem and sustained supply of fibre.

Involving everyone in adaptation efforts—government, industry, academia, the public—will be the most effective approach. Good communication and information exchange will help Canadians address shared problems and pool resources to solve them.



Canada's Partnership with Indigenous Peoples on Climate

Supporting Indigenous climate leadership

First Nations, Inuit, and Métis peoples have been at the forefront of the impacts of climate change. Many Indigenous leaders have reinforced the need to take action to reduce pollution, to adapt to the impacts of climate change, and to improve the ways in which the natural environment is respected and protected. In doing so, Indigenous leadership and knowledge is critical to achieving the foundational changes required to address climate change.

To help support Indigenous peoples advance their climate priorities and adapt to the changing climate, the Government of Canada is committed to renewed nation-to-nation, Inuit-to-Crown and government-to-government relationships with First Nations, Inuit, and Métis peoples, based on the recognition of rights, respect, cooperation, and partnership. The Government of Canada also supports without qualification the United Nations Declaration on the Rights of Indigenous Peoples, including free, prior and informed consent. Supporting self-determined climate action is critical to advancing Canada's reconciliation with Indigenous peoples.

Canada's strengthened climate plan, [A Healthy Environment and a Healthy Economy](#), builds on the foundational principles of Indigenous climate leadership, including:

- Recognizing the unique realities, needs, and priorities of Indigenous peoples across and within distinctions;
- Respecting and promoting self-determination;
- Advancing early and meaningful engagement;
- Incorporating inclusiveness-by-design principles in all of its climate actions;
- Advancing co-development and other collaborative approaches to find solutions;
- Creating a space for Indigenous voices across and within distinctions;
- Positioning Indigenous peoples to have a say at governance tables; and,
- Supporting Indigenous approaches and ways of doing, by acknowledging traditional, local, and Indigenous Knowledge systems as an equal part in policy development, programs, and decision-making.

Since the launch of the [Pan-Canadian Framework on Clean Growth and Climate Change](#), the Government of Canada provided over \$900 million in investments to support Indigenous-led projects on adaptation planning, food security, clean energy, health, infrastructure, climate monitoring, and more.

Climate action funding for Indigenous Peoples

The Government of Canada announced more than \$1.3 billion in climate action funding targeted to Indigenous peoples through Canada's strengthened climate plan, *A Healthy Environment and a Healthy Economy*, and additional investments through [Budget 2021](#). This includes measures to:

- Support First Nations and Inuit as they manage the health impacts of climate change, such as the impacts of extreme weather events, and mental health impacts on youth (\$22.7 million over five years);
- Improve food security in the north, including in Inuit Nunangat (\$163.4 million over 3 years);
- Help transition rural, remote and Indigenous communities from diesel to clean energy (\$376.4 million over 5 years);
- Support greener and more resilient infrastructure, including for large-scale adaptation or mitigation projects (\$290 million over 12 years); and,
- Protect biodiversity through the creation of Indigenous Protected and Conserved Areas and partnerships to restore and enhance wetlands, peatlands, grasslands and agricultural lands to boost carbon sequestration (portion of \$2.3 billion over 5 years for conservation, portion of \$3.16 billion over 10 years for nature-based solutions, portion of \$631 million over 10 years for nature-based carbon sequestration).

Distinctions-based senior bilateral tables on clean growth and climate change

In 2016, the federal government committed to strengthening its collaboration with Indigenous Peoples as partners in climate action. Following joint commitments made by the Prime Minister and the National Leaders of the Assembly of First Nations, Inuit Tapiriit Kanatami and the Métis National Council, the federal government established three distinctions-based senior bilateral tables. These tables are based on the recognition of rights, co-operation, and partnership. They help foster a collaborative approach to ongoing engagement with Indigenous Peoples, and help support Indigenous climate leadership.

Additional information on the creation of the Senior Bilateral Tables on Clean Growth and Climate Change can be found on the [Process Document for Ongoing Engagement on the Pan-Canadian Framework on Clean Growth and Climate Change](#).

First Nations-Canada partnership

The First Nations-Canada Joint Committee on Climate Action (JCCA) was established in fall 2017. Since then, Assembly of First Nations representatives from across Canada and federal officials from various departments meet to discuss climate change priorities and collaborate on climate policy. The JCCA continues to explore opportunities for First Nations to meaningfully participate in the transition to a clean growth economy as climate leaders.

In August 2021, the [JCCA released its third annual report](#) to the Prime Minister and the National Chief of the Assembly of First Nations. The JCCA's annual report documents the positive steps taken towards reconciliation and forging a stronger climate partnership in 2020. This report highlights the Joint Committee's work in 2020 across five key areas:

- Ensuring First Nations' full and effective participation in federal clean growth and climate change programs.
- Empowering First Nations leadership in emerging opportunities for climate action.
- Enabling the meaningful participation of First Nations in the carbon pollution pricing system.
- Developing First Nations-specific indicators and criteria to report on the implementation of climate-related federal funding programs and outcomes for First Nations.

- Fostering intergenerational dialogue on climate change.

Inuit-Canada partnership

The Inuit-Canada Table on Clean Growth and Climate Change was created in 2017 to provide a forum for representatives from Inuit Tapiriit Kanatami, Regional Land Claims Organizations and federal officials from various departments to discuss and advance joint climate priorities. Since then, the Inuit Tapiriit Kanatami has shifted its focus to the National Inuit Climate Change Strategy (NICCS) that advances Inuit-determined actions to strengthen the sustainability and resilience of Inuit Nunangat in the face of a rapidly changing climate and landscape.

To support Inuit knowledge and leadership for successful climate action, the Government of Canada provided \$1 million in summer 2019 to implement the NICCS. This support will help advance Inuit-led activities and initiatives under the following NICCS priority areas:

- Advance Inuit capacity and knowledge in climate decision-making;
- Improve Inuit and environmental health and wellness;
- Improve food security;
- Close the infrastructure gap with climate resilient new builds, retrofits, and Inuit adaptation to changing natural infrastructure; and
- Support regional and community driven energy solutions leading to Inuit energy independence.

Métis-Canada partnership

Since 2017, the Métis Nation-Canada Joint Table on Clean Growth and Climate Change members have built relationships and shared information on joint policy development, and identified Métis-specific considerations for designing federal programs and delivering funding.

Federal departments are working with the Métis Nation to adjust programs and policies under Canada's climate plan. This includes advancing Métis climate change and related health priorities, and shaping community-based climate monitoring initiatives. In 2020, the Métis Nation identified the following priorities to advance Métis Nation climate leadership:

- Capacity-building;
- Collecting Métis traditional knowledge;
- Conducting research & collecting data to guide Métis policy;
- Education and training opportunities in climate change;
- Environmental stewardship and nature-based solutions;
- Emergency management and disaster-risk mitigation;
- Climate change and health;
- Transportation, and;
- Renewable energy and energy-efficiency retrofits



RENEWABLE ENERGY BRINGS ABOUT IMPROVEMENTS IN PEOPLE'S LIVELIHOODS AND HELPS FIGHT CLIMATE CHANGE

Challenges

The Model Forest is situated in Chile's Mediterranean ecoregion, one of the 34 biodiversity hotspots in the world catalogued by "Conservation International". Agriculture, livestock, the use of trees for firewood and charcoal as well as the extraction of humus from the forest (topsoil that is rich in organic matter) are practices that have contributed to the degradation of these forests that are so characteristic of the territory. Several species of the native forest have been declared vulnerable or endangered such as the Northern Belloto (*Beilschmiedia miersii*) and the Southern Belloto (*Beilschmiedia berteriana*).

Moreover, the districts of Coltauco and Doñihue, which are part of the territory influenced by the Model Forest, have been declared by the Ministry of the Environment as areas saturated by the high



Cachapoal Model Forest, Chile
Established: 2008 | Area: 105,000 ha

Facts

- The Model Forest is located in the central part of the country, which is the area with the highest population density and where there is significant pressure on natural resources produced by a variety of forestry and agricultural activities.
- In this area, the forest is valued for the production of firewood and charcoal, the extraction of non-wood forest products such as leaves and fruit, activities such as beekeeping and tourism, and the production of services such as water and soil.



indices of suspended particulate matter in the air, as a result of slash-and-burn practices, forest fires and the misuse of firewood. Luis Martínez, Head of Chile's Special Programs Unit of the National Forest Corporation (Corporación Nacional Forestal), says that Chile could be one of the countries most affected by climate change and, accordingly, the State is concerned with adopting measures to fight and mitigate this phenomenon through lower carbon emissions and the protection of forested areas.

Finding solutions

Since the establishment of the Model Forest in 2008, its partners have been promoting a strategy to contribute to family and local development, and encourage a better relationship between people and natural resources, as well as to cut down on use of firewood as fuel and, accordingly, the emission of gases into the atmosphere. This strategy is based on promoting the use of unconventional forms of renewable energy as a way of encouraging the rational use of the area's natural resources to ensure the ecological integrity of the ecosystem, without overlooking the socio-economic development of the community.

Within the context of the Model Forest, and thanks to opportunities and alliances with several different partners, the actions involve people from the urban and rural parts of the territory who have a certain level of interest in its natural resources and, consequently, in the use of the firewood.

Solar cookers and dehydrators, as well as biodigesters for biogas production, are the main clean energy technologies being used. They make it possible to take advantage of resources such as sunlight and certain agricultural and forest products, thus minimizing the cost of living for these families. The Model Forest also works on awareness, training and the promotion of these technologies in communities, schools and local governments.

Renewable energy is energy that comes from resources that are continually replenished and inexhaustible on a human scale: solar, wind, hydraulic, biomass and geothermal.

Solar cooker and dehydrator

Solar energy can be used to heat water as well as for cooking and drying food. Solar devices such as fruit dehydrators, water collectors and solar cookers help to reduce the use of charcoal and firewood. These technologies also make it possible to take advantage of fruit and other forest materials that would otherwise be thrown away, thus creating an additional source of income and helping to lower air pollution in the communes.

Biodigester

The biodigester uses animal feces and any other degradable material to produce biogas through an anaerobic process. It helps to lower the emission of gases into the atmosphere from animal waste, and reduces the use of firewood and charcoal as fuel. The biogas is used by households for cooking and heating.

Vermiculture

Vermiculture transforms organic waste from agriculture into humus that is used as compost for crops. This practice is aimed at avoiding the extraction of humus, a recurrent practice that is extremely harmful to the regeneration of the forest. It also promotes the development of a sustainable activity for farmers.

Results and impacts

This strategy has made it possible to build alliances with public and private bodies that facilitate the leverage of funds to finance innovative projects connected with the promotion of clean energy, the collective construction of a device and community training in topics such as climate change, renewable energy, the use of firewood and the sustainable management of the native forest. The National Forest Corporation, the National Energy Commission, the Ministry of the Environment, the Foundation for Overcoming Poverty (Fundación Superación de la Pobreza), the municipalities of Doñihue, Coltauco and Las Cabras as well as local organizations such as schools, neighbourhood associations and ecological groups have been key partners in achieving this goal. According to Leonardo Duran, coordinator of the Cachapoal Model Forest, “These types of projects can only be implemented if you have built up a basic group of institutions to contribute funding, knowledge and other elements to help support these processes over time.”

Since 2008 to date, approximately 200 to 250 people have benefited from high investment projects or initiatives in which every family built their own device. Using fruit dehydrators, families can sell their produce on the local market, either directly or through intermediaries. At the same time, the biogas produced by the biodigester results in savings on the monthly gas bill (the equivalent to US\$80), minimizes the use of firewood, and can be used in the production of goods such as jams that generate an additional income for the family. Through these projects, a value chain is being created that is based on the promotion of clean energy. The intention is for these numbers to increase in the future, and to this end, projects are now being carried out in conjunction with several local organizations that are financed by the Ministry of the Environment’s Environmental Protection Fund, in which resources are committed by the organizations and the Model Forest.

These tools help to minimize the use and extraction of firewood, which in turn helps in the upkeep of the goods and services provided by the forest, as well as in limiting the emission of gases into the atmosphere, thus contributing to the great challenge represented by climate change. These different initiatives illustrate the positive effects of unconventional renewable energy in aspects such as family economy, forest exploitation and environmental awareness. “To reinforce this work as a Model Forest, the economic and environmental impacts of the use of these technologies needs to be monitored,” points out Leonardo Duran. This process enables the construction of a social fabric, a critical mass of stakeholders who already look upon the use of unconventional renewable energies as a way of life, are trained in the construction and use of these devices and are aware of the benefits for the environment, their families and local development.

“The Model Forest also seeks to have a political impact,” adds Leonardo Duran, “so that in the future, clean energy and other topics may be included in the curriculum as part of environmental education as well as in development policies that are being implemented by institutions at a local level.”

To find out more

- International Model Forest Network: imfn.net
- Video: youtu.be/C0t1DeFUdnw

The International Model Forest Network brings people together to test and apply innovative approaches to the sustainable management and use of the world’s landscapes and natural resources.

IMFN.NET



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