REPORT

Canada in a Changing Climate

Regional Perspectives

Government of Canada / Gouvernement du Canada

Canada

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Canada in a Changing Climate: Regional Perspectives Report

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Key Findings

Canada in a Changing Climate: Regional Perspectives Report was led by Natural Resources Canada and provides regional perspectives on how climate change is impacting our communities, environment and economy, and how we are adapting to reduce risk. The report assesses current literature and knowledge on climate change impacts and adaptation, and includes case stories that feature examples of adaptation in practice. Each regional chapter discusses key vulnerabilities, risks and challenges; new and innovative approaches to adaptation; Indigenous knowledge and perspectives; capacity to adapt to climate change impacts; and knowledge gaps and emerging issues. Regional chapters include: Atlantic Provinces, Quebec, Ontario, Prairie Provinces, British Columbia and Northern Canada. The report is a product of Canada in a Changing Climate: Advancing our Knowledge for Action, Canada's national climate change assessment process.

Key Findings from Canada in a Changing Climate: Regional Perspectives Report

1. **Canada's regions are experiencing climate change in different ways, with varied impacts on communities, ecosystems, infrastructure and natural resources**. Provincial, territorial and local governments are responding with adaptation plans, policies and actions to address priority risks, but further work and resources are needed to better plan for climate change impacts at the regional level, as well as enhance regional capacity on adaptation (see all chapters of this report).

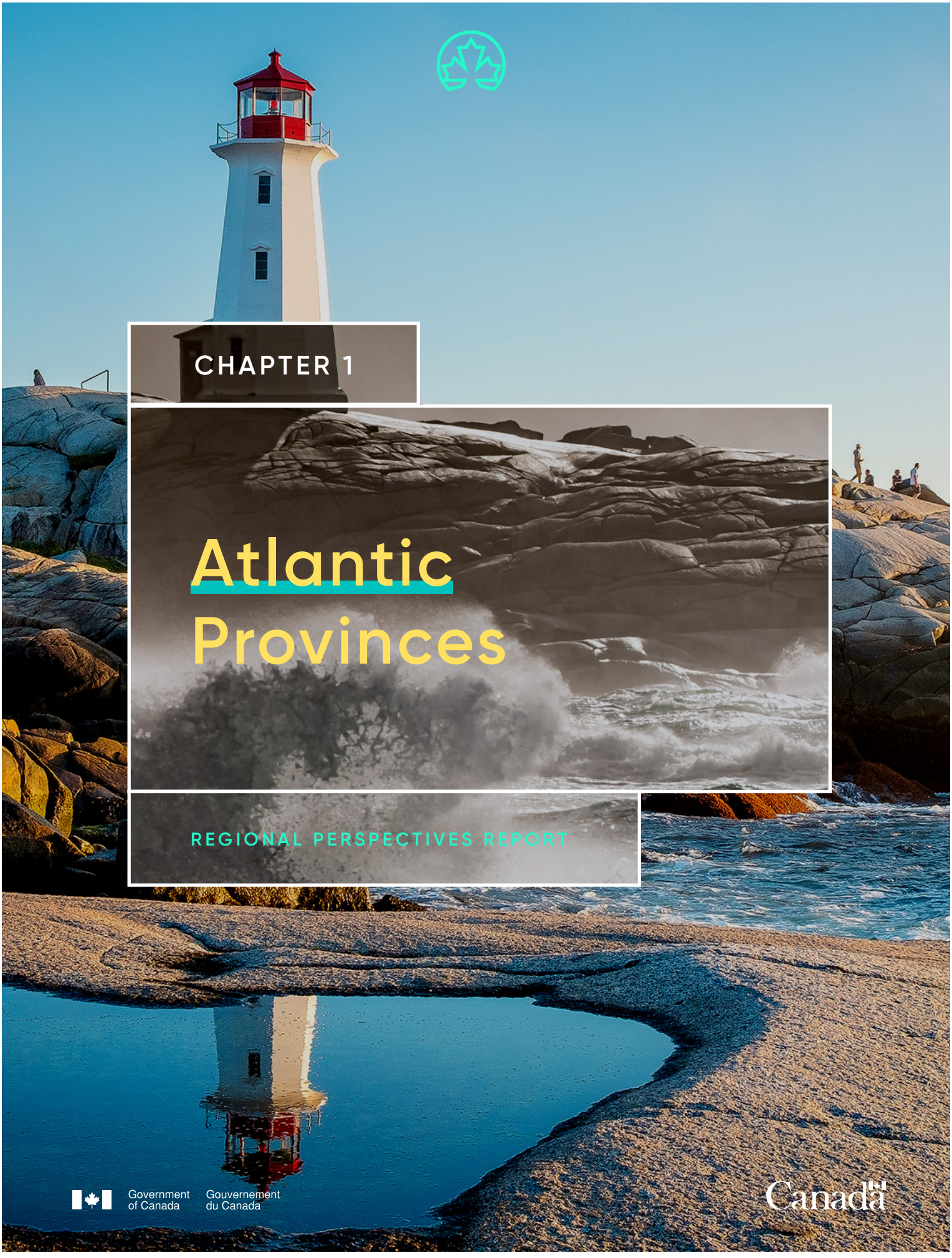
2. **Climate change is increasing human health risks in all of Canada's regions and deepening existing inequities**. Climate change is having impacts on human health, including through growing risks related to extreme heat, extreme weather, vector-borne diseases, and changes to sea ice and permafrost in the north. While there are promising examples of adaptation planning and implementation at the regional level to address health risks, more work is needed to better understand and respond to climate change impacts on mental health and existing inequities (see all chapters of this report).

3. **Adaptation is vital for Canada's agriculture and natural resource sectors to remain competitive in a changing climate**. Across Canada's regions, the agriculture, energy, mining and forestry sectors face risks related to changes in temperature and rainfall patterns and the emergence of new pests. Producers in all climate-sensitive sectors need to adapt their decision making, practices and operations to changing climate conditions (see Atlantic Provinces chapter; Ontario chapter; Prairie Provinces chapter; British Columbia chapter).

4. **Collaboration is key to managing water resources threatened by climate change**. Rising temperatures and changing precipitation patterns are affecting the quality and availability of water resources in several regions across Canada. Approaches such as adaptive management, enhanced collaboration and transboundary coordination between different orders of government and stakeholders is needed to reduce negative impacts on agriculture, human health and industry (see Québec chapter; Ontario chapter and Prairie Provinces chapter).

5. **Indigenous Peoples are deeply affected by climate change, and draw on their knowledge and inherent resilience to address impacts**. Climate change is altering landscapes and ecosystems across Canada's regions, which sustain hunting, fishing and other land-based activities that are essential to the culture and identify of Inuit, First Nations and Métis. There are growing examples of Indigenous-led adaptation plans and actions, which integrate Indigenous Knowledge and draw on Indigenous leadership in environmental stewardship and governance of natural resources (see Atlantic Provinces chapter; Ontario chapter; British Columbia chapter and Northern Canada chapter).

6. **Preserving ecosystems and implementing nature-based approaches can play an important role in climate change adaptation across Canada's regions**. Forests, wetlands and coastal vegetation help address climate change through the delivery of services, including reducing erosion and flood risks. Nature-based approaches are increasingly being used across Canada's regions to address climate change (see Atlantic Provinces chapter; Québec chapter and Ontario chapter).



CHAPTER 1

Atlantic Provinces

REGIONAL PERSPECTIVES REPORT

Government of Canada
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Canada

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Key messages

Infrastructure is being threatened by increased flooding and erosion (see section 1.2)

Climate change is amplifying existing flood risks in Atlantic Canada's coastal areas and in locations that are prone to overland flooding and erosion. Recognizing the risks, a range of adaptation measures are being implemented, including changes to infrastructure design, such as using engineered protective structures, as well as nature-based approaches to protect the coast.

Climate change is exacerbating risks to health and well-being (see section 1.3)

People living in Atlantic Canada are facing significant risks to their physical and mental health and well-being from climate change. Climate change exacerbates health issues associated with existing vulnerabilities in the region, which are influenced by factors such as socioeconomic status, ethnicity, employment and living arrangements. Adaptation measures include public education, vulnerability mapping and actions to address health risks and their underlying factors.

Indigenous experiences inform adaptation in Atlantic Canada (see section 1.4)

The Mi'kmaq, Wolastoqiyik and Peskotomuhkati Nations of the Wabanaki Confederacy have occupied the Maritimes since time immemorial and have adapted to changes in climate and the environment over countless generations. Partnerships with, and leadership by, local Indigenous peoples are vital to ensuring that the knowledge, perspectives and experiences that they hold from living on the land, inform adaptation in their communities and in the region.

Forestry, agriculture and fisheries are vulnerable to climate change (see section 1.5)

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.

Building adaptive capacity will strengthen resilience (*see* section 1.6)

Adaptive capacity in Atlantic Canada is often constrained by limited human and financial resources. Partnerships and collaboration between different stakeholders—including governments, NGOs, academia and the private sector—are important for driving adaptation in the region. Outreach, public education and effective communication are key for building adaptive capacity in Atlantic 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.

1.1.1 Demographic profile

Atlantic Canada makes up 6.5% of Canada's population. The population in the region grew by only 2.2% over the past 20 years, while the country as a whole experienced a 22.9% increase over the same time period (*see* Table 1.1). Atlantic Canada's population is ageing, with projections estimating that 31.1% of the total population will be over the age of 65 years by 2038, compared with the national average of 25.5% (Statistics Canada, 2015a).

Table 1.1: Past, present and future population demographics for individual Atlantic Provinces, the Atlantic Canada region and Canada as a whole

	N.B.	N.L.	N.S.	P.E.I	ATLANTIC CANADA	CANADA
Population (2018)	770,633	525,355	959,942	153,244	2,409,174	37,058,856
Population change (1998–2018)	2.7%	-2.7%	3.0%	12.8%	2.2%	22.9%
Population change (2018–2038*)	-2.3%	-12.9%	-1.5%	18.9%	-3.0%	17.4%
Immigrants (2018–2019)**	5,076	1,653	6,395	2,267	15,391	313,601
Emigrants (2018–2019)**	601	152	1,047	54	1,854	51,290

	N.B.	N.L.	N.S.	P.E.I	ATLANTIC CANADA	CANADA
Net interprovincial migration (2018–2019)	1,669	-2,597	3,632	662	3,366	0
Percent of population aged 65+ (1998)	12.9%	11.3%	13.2%	13.2%	12.7%	12.3%
Percent of population aged 65+ (2018)	20.8%	20.5%	20.4%	19.6%	20.5%	17.2%
Percent of population aged 65+ (2038*)**	31.0%	33.9%	30.4%	27.4%	31.1%	25.5%
Median age (1998)	36.5	35.9	36.8	35.9	n/a	36
Median age (2018)	45.9	46.5	45.1	43.6	n/a	40.8

The projected data were derived using the M3 medium growth scenario. Sources: Statistics Canada, 2019b; Statistics Canada, 2015a for data marked with a single asterisk; Statistics Canada, 2020a for data marked with double asterisks; Statistics Canada, 2019c for data marked with triple asterisks.

For the period 2013–2017, the median annual income of residents in each Atlantic province was below the national median of $33,766 (Statistics Canada, 2019a). Over 46% of Atlantic Canadians live in rural areas and small communities, compared with 18.6% nationwide (Statistics Canada, 2019d). Many Atlantic communities are dealing with declining, ageing populations and diminishing economic resources leading to less capacity to adapt to risks, changes and hazards (Vasseur and Catto, 2008). However, communities with long-term residents who have strong local ties to the region can have enhanced adaptive capacity (Vasseur and Catto, 2008).

The Mi'gmaq, Wolastoqiyik and Peskotomuhkati Nations of the Wabanaki Confederacy have occupied Atlantic Canada since time immemorial (Indigenous and Northern Affairs Canada, 2013; Francis, 2003). The Atlantic region is also home to 3.5% of the country's Inuit population (although this is mainly in Nunatsiavut, northern Labrador; *see* Northern Canada chapter), 7.5% of the First Nations population and 7.2% of the Métis population (Statistics Canada, 2017).

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).

1.1.3 Changes in climate

Between 1948 and 2016, the annual mean temperature across Atlantic Canada increased by 0.7°C, and the normalized annual precipitation increased by 11% (Zhang et al., 2019). In contrast to other regions in Canada, warming has been driven by increases in summer temperature rather than increases in winter temperature (Cohen et al., 2019; Zhang et al., 2019). Climate change impacts can result from increases in mean temperature and mean precipitation over time, as well as changes in climate extremes. Projected trends for a number of climate variables vary within and among individual provinces and local regions (*see* Figure 1.1 and Table 1.2).

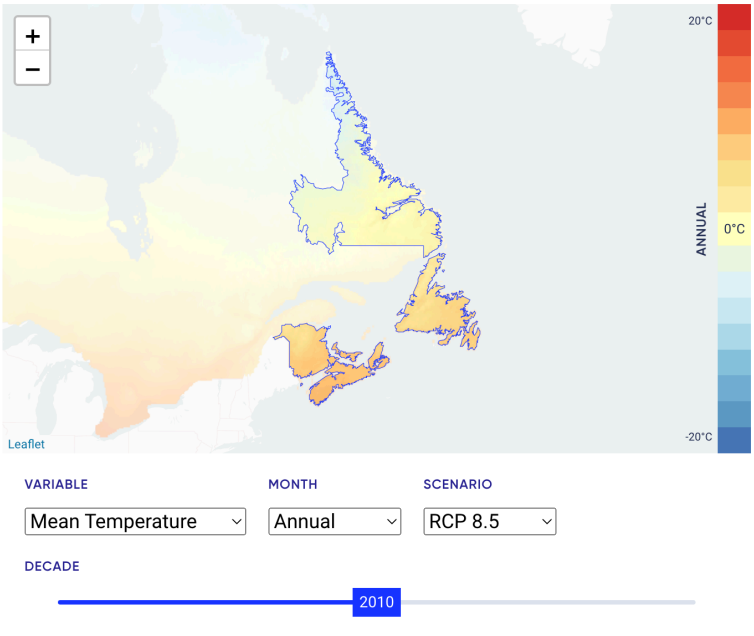

Figure 1.1: Interactive regional map of the Atlantic Provinces that draws from climatedata.ca and visualizes various climate variables from 1980 to 2100 using a high emissions RCP8.5 scenario.

Table 1.2: Projections of different climate variables for each Atlantic Province

	1976-2005	2021-2050				2051-2080			
		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*
Temperature									
Mean Temp, ºC									
NB	4.5	5.4	*0.9*	7.9	*3.4*	7.4	*2.9*	10.3	*5.8*
NL	-1	-0.2	*0.8*	2.5	*3.5*	1.6	*2.6*	5.1	*6.1*
NS	6.4	7.1	*0.7*	9.6	*3.2*	8.8	*2.4*	11.8	*5.4*
PE	5.9	6.6	*0.7*	9.2	*3.3*	7.3	*1.4*	10.4	*4.5*
Very Hot Days (+30ºC), Number of days									
NB	5	5	*0*	23	*18*	14	*9*	49	*44*
NL	0	0	*0*	3	*3*	1	*1*	7	*7*
NS	1	1	*0*	12	*11*	5	*4*	32	*31*
PE	1	1	*0*	14	*13*	2	*1*	25	*24*
Very Cold Days (-30º), Number of days									
NB	2	0	*-2*	2	*0*	0	*-2*	0	*-2*
NL	12	1	*-11*	9	*-3*	0	*-12*	3	*-9*
NS	0	0	*0*	0	*0*	0	*0*	0	*0*
PE	0	0	*0*	0	*0*	0	*0*	0	*0*

	1976-2005	2021-2050				2051-2080			
		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*
Precipitation									
Total Precipitation (mm)									
NB	1106	1005	*-9.1%*	1350	*22.1%*	1054	*-4.7%*	1433	*29.6%*
NL	937	916	*-2.2%*	1118	*19.3%*	961	*2.6%*	1183	*26.3%*
NS	1328	1207	*-9.1%*	1605	*20.9%*	1240	*-6.6%*	1668	*25.6%*
PE	1090	968	*-11.2%*	1334	*22.4%*	997	*-8.5%*	1371	*25.8%*
Other Variables									
Tropical Nights (Days with Tmin > 20ºC), Number of nights									
NB	0	0	*0*	6	*6*	2	*2*	23	*23*
NL	0	0	*0*	1	*1*	0	*0*	3	*3*
NS	0	0	*0*	7	*7*	2	*2*	25	*25*
PE	1	0	*-1*	13	*12*	1	*0*	25	*24*
Date of Last Spring Frost									
NB	May 15	Apr 22	*-23 days*	May 17	*+2 days*	Apr 8	*-37 days*	May 8	*-7 days*
NL	Jun 5	May 13	*-23 days*	Jun 6	*+1 day*	Apr 29	*-37 days*	May 30	*-6 days*
NS	May 8	Apr 13	*-25 days*	May 11	*+3 days*	Mar 30	*-39 days*	May 1	*-7 days*
PE	May 7	Apr 10	*-26 days*	May 11	*+4 days*	Apr 2	*-34 days*	May 7	*0 days*

	1976-2005	2021-2050				2051-2080			
		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*	median	*versus 1976-2005*
Date of First Fall Frost									
NB	Sept 27	Sept 28	*+1 day*	Oct 24	*+27 days*	Oct 9	*+12 days*	Nov 9	*+43 days*
NL	Sept 24	Sept 26	*+2 days*	Oct 16	*+22 days*	Oct 5	*+11 days*	Oct 27	*+33 days*
NS	Oct 15	Oct 16	*+1 day*	Nov 14	*+30 days*	Oct 29	*+14 days*	Nov 28	*+44 days*
PE	Oct 24	Oct 19	*-5 days*	Nov 19	*+26 days*	Oct 24	*+0 days*	Nov 25	*+22 days*

Note: Projections were made using the IPCC's Representative Concentration Pathway (RCP) 4.5 as the "medium emissions scenario" and RCP8.5 as the "high emissions scenario". Source: Climate Atlas of Canada, 2019.

Increases in relative sea level are of particular concern for the region, with the projected rise in sea level being higher than the global average in most areas of Atlantic Canada (Greenan et al., 2019; Atkinson et al., 2016). The relative sea level for the region is projected to increase by 75–100 cm by 2100 under a high emissions scenario (Cohen et al., 2019; Atkinson et al., 2016). Rising sea level will lead to an increased frequency of coastal flooding events. For example, a 20cm rise in sea level in Halifax—as is projected to occur within the next two to three decades under all emission scenarios—will result in a four-fold increase in the frequency of coastal flooding within the municipality (Greenan et al., 2019). The coastline will be further impacted by reduced sea ice in winter, which will result in higher energy waves reaching the coast during winter storm events and will exacerbate the risk of damage to coastal infrastructure and ecosystems (*see* Figure 1.2; Greenan et al., 2019).

Figure 1.2: Storm surge event at North Rustico Harbour, Prince Edward Island. Photo courtesy of Don Jardine.

Annual streamflow is projected to increase across most of the region. Studies of the Saint John, Nashwaak, Canaan, Kennebecasis, Restigouche and the Miramichi River watersheds in New Brunswick (El-Jabi et al., 2013), the Pinus River Basin in Labrador (Roberts et al., 2012) and the Sackville River in Nova Scotia (CBCL Consulting Engineers, 2017a) quantify the projected changes. It is difficult to predict how increased annual streamflows will impact the frequency and magnitude of inland flooding, since those events are influenced by a combination of many factors, which tend to differ across the region. For example, in general, inland flooding is caused by:

- rain combined with snowmelt and ice jamming in Newfoundland and Labrador;
- torrential rainfalls, sudden thaws, and infrastructure failures in Nova Scotia;
- extreme precipitation events, often as a result of extratropical storms in Prince Edward Island; and;
- rain events, rain-on-snow events, and/or ice jamming in New Brunswick (Burrell, 2011).

1.1.4 Previous work on adaptation

In Atlantic Canada, non-governmental organizations, academic institutions, municipal and provincial governments, and Indigenous communities and organizations have all played a role in past and current work on climate change adaptation. Early work focused on collecting baseline information about regional climate change impacts and supporting climate change risk assessments for different sectors, building collaborative networks, and carrying out Municipal Climate Change Adaptation Plans (e.g., in Nova Scotia). The Atlantic Climate Adaptation Solutions Association (ACASA)—a partnership of the four provincial governments and regional stakeholders—supported collaborative efforts to develop information and tools between 2009 and 2016, primarily for municipalities, to address common climate change impacts (ACASA, n.d.).

These jurisdictions have built on preliminary work to further develop adaptation programs that focus on enhancing capacities, and developing and implementing adaptation plans or strategies, as well as tailored risk assessments and tools. Where unique challenges existed, ACASA also supported projects such as a cost-benefit analysis of transportation adaptation options for the Chignecto Isthmus in the Tantramar region (ACASA, n.d.).Indigenous communities throughout Atlantic Canada have advanced adaptation work. For example, Elsipogtog, L'nuiMenikuk and Esgenoopetitj Mi'gmaq communities have been historically vulnerable to overland flooding, which could intensify with climate change. Through partnering with Indigenous Services Canada, projects are underway in each of these communities to repair flood-damaged homes and infrastructure, while implementing small-scale risk-reduction measures, such as draining improvements, raising flood-prone structures, and doing infilling and grading work to build resiliency (Indigenous Services Canada, 2020; Prairie Climate Centre, 2019a, b).

1.1.5 Chapter approach

This chapter builds on past assessment reports and draws heavily on content provided by local and regional practitioners, non-governmental organizations, consultants, scientists and government. Contributions are based on regional expertise, and lessons learned from successes and challenges, not all of which are available in peer-reviewed journals. The key messages were developed through an iterative prioritization process during workshops and interviews with practitioners and experts. A team of authors stepped forward (responding to broadly extended invitations) to develop the selected key messages further. Indigenous participants in the workshops and meetings emphasized the need to develop a stand-alone key message on Indigenous perspectives, rather than incorporating these into each of the other key messages.

The chapter presents five key messages on themes related to climate change impacts and adaptation in Atlantic Canada. The themes are as follows: risk to infrastructure due to overland flooding and sea-level rise; community health and well-being; Indigenous communities; natural resource industries; and building capacity to adapt to climate change. The knowledge gaps and research needs section discusses other high-priority climate change issues that were identified during the writing process, but where literature was lacking on adaptation approaches (*see* Section 1.7.1).

1.2 Infrastructure is being threatened by increased flooding and erosion

Climate change is amplifying existing flood risks in Atlantic Canada's coastal areas and in locations that are prone to overland flooding and erosion. Recognizing the risks, a range of adaptation measures are being implemented, including changes to infrastructure design, such as using engineered protective structures, as well as nature-based approaches to protect the coast.

Coastal and overland flood risks vary across the Atlantic region. The region's coastline is vulnerable to flooding due to sea-level rise and storm surge, and wave-induced erosion. Major rivers and tributaries can cause overland flooding in the spring—due to snowmelt and rain—and in late autumn and through the winter, when the frozen ground is impervious and agricultural fields are without cover crops. These impacts, if not addressed, can lead to the failure of critical infrastructure systems and an interruption to core services, affecting public safety and threatening the ability of communities to sustainably deliver services. Adaptation to reduce risks from flooding requires the use of approaches that are customized for local circumstances. Common default strategies include raising and/or protecting specific infrastructure in its existing location, but these may have serious limitations in the long term. An increase in the availability, accessibility and precision of hazard maps is enabling the proactive consideration of flood risk in infrastructure design and planning. Alternative approaches, though not yet broadly used, include the use of nature-based approaches to dissipate or slow down water before it affects an asset, as well as managed retreat and relocation.

1.2.1 Introduction

Communities in Atlantic Canada face a substantial risk of coastal and inland flooding due to climate change. Drivers of climate change impacts on the coast—including sea-level rise and storm surges—differ in the relative severity of their impacts—such as erosion and flooding—throughout Atlantic Canada. This reflects differences in the physical environment from one location to another, such as elevation, type of coastal system (e.g., cobble beach, sandstone cliff), wave exposure and other factors (Savard et al., 2016). Changes in sea level are driven by a combination of local, regional, hemispheric and global factors (Atkinson et al., 2016). As a result, historic and projected changes in sea level vary across Atlantic Canada, with many areas projected to experience a rise in sea level that is greater than the global median (*see* Figure 7.16 in Greenan et al., 2019). More specifically, sea-level rise is projected to be within the range of 75–100 cm before the end of the 21st century for Newfoundland, Nova Scotia, New Brunswick and Prince Edward Island (Greenan et al., 2019). Sea level is projected to rise only slightly in Labrador due to isostatic rebound (Greenan et al., 2019). The assessment of future changes to sea level continues to evolve with the use of updated observations and climate modelling.

In addition to coastal flood risks, some areas—such as the coastline of the Northumberland Strait in New Brunswick, and Prince Edward Island—are particularly susceptible to coastal erosion due to highly erodible sandstone bedrock and the location of many communities in low-lying coastal areas (Vasseur and Catto, 2008). Coastal erosion is both a long-term and a short-term process. Long-term erosion can be produced by

sea-level rise, but also by waves—for example, if the predominant characteristics of the waves change (e.g., in direction). Short-term erosion is caused during storms, so increases in storm activity will increase erosion over the long term (Atkinson et al., 2016). Furthermore, reductions in seasonal sea-ice cover increase the exposure of the coastline to storms, which can result in flooding and accelerated erosion during winter storm events (Greenan et al., 2019; Lemmen et al., 2016).

Overland flooding events in Atlantic Canada are mainly the result of significant rainfall events due to hurricanes; extratropical transitions; autumn storms; ice jams; snowmelt; or a combination of these factors (Newfoundland and Labrador Department of Municipal Affairs and Environment, 2019; Environment and Climate Change Canada, 2010). Extreme daily precipitation is projected to increase in Canada, with stronger projected increases under high emission scenarios and later in the 21st century. For the high emissions scenario (RCP8.5), the projected median increase in the 20-year annual maximum precipitation event for Atlantic Canada is 14% by 2031–2050 and 30% by 2081–2100 (Zhang et al., 2019). As spring melt occurs earlier due to higher temperatures, and rain-on-snow events increase, this will result in a shift towards earlier floods, ice jams and rain-on-snow events (Bonsal et al., 2019), leading to a greater amount of runoff into river and stream systems. Rapid runoff from steep slopes and paved surfaces can result in flooding almost immediately during or after a storm—particularly in areas with thin soil cover, shallow bedrock and steep slopes, which characterize much of Newfoundland and Labrador (PIEVC, 2008). Historic settlement along rivers and the coast places people, infrastructure and services in zones of increasing flood risk. In many cases, development pressures, advances in construction technologies and limited land-use regulation have allowed for unbridled waterfront development in high-risk areas (Cutter et al., 2018).

Coastal and overland flooding has impacts on infrastructure, influencing all aspects of life and socio-economic activity both directly and indirectly. Direct impacts include damage to critical transportation infrastructure between regions that are connected by a single road link, thereby increasing their vulnerability, such as the Chignecto Isthmus connecting New Brunswick to Nova Scotia (Rapaport et al., 2017), the Canso Causeway to Cape Breton Island, the Trans-Canada Highway through southwestern Newfoundland, and the Trans-Canada Highway at Jemseg (MacKinnon, 2019). Work is ongoing in some cases, to identify adaptation approaches to decrease the vulnerability of these transportation links (e.g., Chigneto Isthmus; Parnham et al., 2015).

Some communities along the Wolastoqey (Saint John River), including First Nation communities (e.g., Kingsclear First Nation, St. Mary's First Nation and Oromocto First Nation) also have critical infrastructure that is vulnerable to climate change impacts. This includes communities with sewage treatment lagoons located in close proximity to the river, where more severe spring thaw resulting from snow and ice melt in rivers and flooding have caused contaminated overflow. This presents health hazards for those communities (Radio-Canada, 2019a; Government of New Brunswick, 2014, Lantz et al., 2012). Communities that are partially or entirely reliant on ferry or bridge service are also subject to weather-related disruptions, affecting areas such as the Kingston Peninsula in New Brunswick and isolated communities in Newfoundland and Labrador.

1.2.2 Adaptation approaches

The main strategies in coastal adaptation fall into three categories: protection, accommodation and avoidance/retreat (Lemmen et al., 2016; van Proosdij et al., 2016). Land-use planning, engineering and nature-

based approaches provide a variety of options across each of these strategies, although accurate flood hazard tools are necessary to reduce or avoid future flood risks for communities and infrastructure. While the use of "soft" approaches (e.g., shoreline restoration using plants) and "hard" engineering approaches (e.g., building a seawall) are currently the most common approaches to adaptation (*see* Figure 1.3), discussions about community relocation are beginning in some areas that are particularly at risk, recognizing that this is rarely a desirable option among residents (Mercer Clarke et al., 2016).

1.2.2.1 Hazard risk assessments

Flood hazard maps, which identify areas that are prone to seasonal or projected flooding, are valuable tools for public outreach and engagement. The information provided by such tools allows communities to conduct detailed vulnerability assessments that consider projected elevations of floodwater, supporting individual citizens, municipalities, planning authorities, infrastructure and utility owners to make well-informed decisions on how best to adapt assets and properties to risks. Up-to-date flood hazard maps, which are essential for decision-makers (Institute for catastrophic Loss Reduction 2019), are under development for some areas in Atlantic Canada.

For example, New Brunswick's Climate Change Action Plan, Transitioning to a Low-Carbon Economy, recognizes the need to update flood hazard maps to ensure public safety and facilitate land-use planning efforts across the province (Government of New Brunswick, 2016). The province is undertaking both coastal and overland flood risk assessments using updated flood hazard maps. When the data become publicly available, users will be able to easily identify which areas and infrastructure are at risk. Newfoundland has been updating its flood hazard maps since 2005 (Government of Newfoundland and Labrador, n.d.a). Similar projects are underway in both Prince Edward Island and Nova Scotia, where coastal hazard maps and guidance for municipalities on development in floodplains are being developed (Government of Prince Edward Island, 2018).

Many municipalities across Atlantic Canada have updated their flood risk mapping and made changes to municipal plans, regulations and by-laws based on those maps. For example, the Town of Paradise (Newfoundland and Labrador) included the following policy in its most recent Municipal Plan, adopted in 2016, prior to completion of the flood-risk study: "6.4.1 (5) When completed, incorporate the recommendations of a Waterford River Floodplain Study into the Municipal Plan and Development Regulations consistent with provincial floodplain policy" (Town of Paradise, 2016, p. 51). The City of Mount Pearl (Newfoundland and Labrador) has adopted the provincial flood risk mapping and has updated its mapping to show the new flood zones (City of Mount Pearl, n.d.). The city is also studying the Waterford River area in relation to establishing the city centre and how zoning relates to the provincial flood risk mapping (Howell, 2020). These exercises allow for enhanced understanding of potential short- and long-term impacts for specific locations, which helps to inform adaptation measures.

Erosion hazards have been assessed in New Brunswick (Government of New Brunswick, n.d.a), and for the island of Newfoundland based on sensitivity to short-term erosion using a Coastal Erosion Index (Catto, 2011), whereas long-term coastal erosion resulting from relative sea-level rise was assessed using a modification of the Coastal Sensitivity Index (Shaw et al., 1998). Erosion risk assessments were recently

conducted in various locations across southern and central Labrador (Catto, 2019), and the Government of New Brunswick provides historical coastal erosion data on its GEONB website geonb.ca.

1.2.2.2 Land-use planning and development control

More stringent land-use planning measures, such as development regulations with minimum horizontal and vertical setbacks, could better direct the placement of new infrastructure away from known flood-risk areas. Despite many municipal climate planning documents, there are still numerous places where land use plans and by-laws either do not exist (for example, in some unincorporated areas of New Brunswick) or do not reflect current and future climate risks (only 34% of New Brunswick municipalities had assessed risk as of 2020; Government of New Brunswick, 2020).

A number of planning-related initiatives at the provincial and municipal scale are designed to advance adaptation action. Nova Scotia's new Coastal Protection Act limits development, renovations and expansions in vulnerable coastal areas (Nova Scotia Legislature, 2019). In New Brunswick, municipalities facing the greatest coastal hazards were required to complete vulnerability assessments and adaptation plans by 2020. New Brunswick's 2016 Climate Change Action Plan (Government of New Brunswick, 2016) identifies municipalities as high-risk based on historical events, such as those that caused significant flooding or erosion, damaged infrastructure or property, or affected access or emergency response. New Brunswick's Climate Action Plan further commits to phasing in the mandatory preparation and implementation of local adaptation plans for those municipalities that also apply for provincial infrastructure funding. These requirements have generated widespread awareness of potential climate change impacts on coastal municipalities. Similarly, in Nova Scotia, communities are obliged to have climate change adaptation plans in place for them to receive funding through the Canada Community-Building Fund, formerly called the federal Gas Tax Fund, and the province has developed a guidebook to support municipalities in this regard (Savard et al., 2016; Fisher, 2011).

1.2.2.3 "Hard" engineering approaches

Throughout Atlantic Canada, private property owners, municipalities and industries almost exclusively use "hard" infrastructure—such as rock or other material (called riprap) and seawalls—to protect their properties against coastal erosion. Although naturalized shorelines are recognized by coastal ecosystem practitioners to be more resilient and more cost-effective over the long term in certain situations (RVCA, 2011), it has been extremely difficult to discourage private property owners from using "hard" engineered approaches (*see* Figure 1.3). Engineered projects using hard infrastructure may generate more of a sense of security and of being able to withstand climate change impacts. This may act as a deterrent to considering alternatives, such as natural shorelines and natural infrastructure. Larger-scale engineering projects require professional expertise for design, construction (*see* Case Story 1.1) and maintenance. Periodic re-evaluation of "permanent" structures in light of changing exposure to climate change hazards is also important.

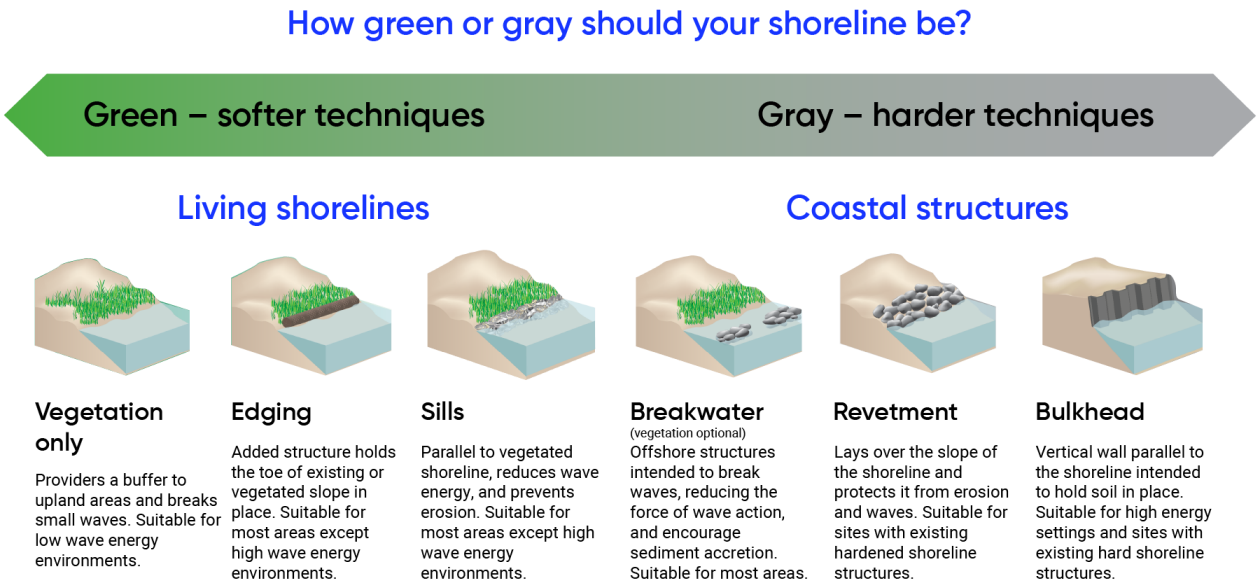

Figure 1.3: A continuum of green ("soft") to gray ("hard") shoreline stabilization techniques. Source: National Oceanic and Atmospheric Administration, 2015.

Engineering solutions are frequently preferred, and a common default strategy is to raise and/or protect the asset in its existing location. For example, rock armouring combined with the raising of roads may be a practical solution for the short to medium term, if designed in a way that reduces negative impacts on shoreline processes, while meeting functional requirements over its intended lifetime (*see* Figure 1.4; Leys, 2020). Indigenous Services Canada works with First Nations to support structural mitigation projects, such as dykes and seawalls. After the 2010 tidal surge at Eel River Bar (New Brunswick), a 600-metre seawall was erected to protect some of the most vulnerable areas (Gillis, 2020).

Innovative "hard" engineered solutions that incorporate natural infrastructure can help to preserve local assets, while providing co-benefits such as creating habitat for benthic flora (*see* Case Story 1.1; Leys, 2020). Integrated planning processes can be critical to achieving a successful outcome in cases where "hard" engineering approaches alone are insufficient—especially for larger-scale projects (*see* Case Story 1.1).

Figure 1.4: Rock revetment, combined with beach openings, used to protect the highway embankment at the entrance to Fundy National Park in Alma, New Brunswick, at low tide. Photo courtesy of Doug Watson, Parks Canada.

Case Story 1.1: Intertidal reefs at Souris, Prince Edward Island

The Town of Souris, Prince Edward Island, is a coastal community that is dependent on tourism and fishing. Similarly to other coastal communities in Prince Edward Island, Souris has been forced to deal with storms and wave action that have been eroding its sandstone shoreline and threatening its infrastructure. The causeway into the town is a vital conduit for the local economy and is a popular beach for tourists. In recognition of its vulnerability (Jardine, 2012), various approaches have been used to protect the causeway infrastructure, including Gabion baskets, armourstone, and a timber crib and steel pile wall. These efforts have supported local economic growth, such as the expansion of the Souris Beach Gateway Park, new commercial outlets and a playground.

Traditional armouring approaches, however, require periodic and sometimes costly maintenance over the long term. In some situations, this armouring approach can also accelerate erosion and cause the depletion of valuable sand on beaches. With that in mind, a project to implement a naturalized infrastructure installation in Prince Edward Island was initiated in 2018 (Davies and Thompson, 2019). Two intertidal reefs were designed by the provincial government to increase the resilience of the beach and dune system, while protecting the causeway and park infrastructure (*see* Figure 1.5). The reefs act as protective barriers against wave action on the shore and, furthermore, are helping to replenish the beach as a result of wave attenuation and subsequent deposition of sediment behind the reefs. The reefs also provide a natural environment for benthic flora to grow. Finally, the reefs are constructed using Prince Edward Island sandstone, which is not only less expensive than traditional imported granite, but also blends in perfectly with the surrounding sediment as it slowly degrades over time.

Figure 1.5: Intertidal reefs at low tide in Souris, Prince Edward Island, July 2018. Photo courtesy of Vincent Leys.

1.2.2.4 Nature-based approaches

"Nature-based approaches" is used as an umbrella term covering a range of approaches to adaptation that are nature-driven (*see* Ecosystem Services chapter of the National Issues Report). This includes, among others, nature-based solutions and natural infrastructure. Natural infrastructure is defined as the "strategic use of networks of natural lands, working landscapes and other open spaces to conserve ecosystem values and functions, and to provide associated benefits to human populations" (Allen, 2014). Nature-based infrastructure, often referred to as "green infrastructure" or "soft infrastructure," includes the use of engineered or human-made systems that resemble natural systems and function naturally. Both natural and nature-based infrastructures provide ecosystem services that enhance resilience (e.g., wetlands contributing to reduced flood risk and enhanced water quality; *see* Ecosystem Services chapter of the National Issues Report). On a regional scale, the Maritime Natural Infrastructure Collaborative (MNIC) identifies the following challenges and opportunities related to natural infrastructure: building capacity; knowledge and awareness of its importance and use; supporting the development of community engagement tools that can facilitate knowledge integration into land use, watershed and climate change adaptation planning; and working directly with municipalities to implement local adaptation projects (*see* Case Story 1.2).

Case Story 1.2: Using natural infrastructure to create healthy and resilient communities

The Maritime Natural Infrastructure Collaborative (MNIC, 2017) is a multi-sector network of NGOs, government, planners and academics from New Brunswick, Nova Scotia and Prince Edward Island (ICF, 2018). It raises awareness about the important role that natural infrastructure plays in helping communities to remain healthy and resilient in the face of climate change. For example, a series of Natural Infrastructure Learning Days brought participants to various natural infrastructure project sites to learn how naturalized stormwater ponds, rain gardens and restored river banks can help to reduce inland flood risks and enhance local water quality. These events attracted a variety of professionals and students, many of whom wanted to increase their knowledge and awareness about the value of natural infrastructure as an effective adaptation approach (New Brunswick Environmental Network, 2018a).

The use of nature-based approaches for coastline adaptation in the Atlantic Provinces—such as protective vegetation or wetlands in coastal environments—is less common than engineered structures, in part because these techniques are less familiar and may not be as recognized as effective (van Proosdij, 2021). Implementation of such measures may also require changes in land-use and development regulations to leave open space and preclude building. However, there are promising examples of nature-based approached being used in the region (*see* Case Stories 1.3; 1.4). A large portion of the natural assets and restored natural infrastructure currently being maintained has benefited from conservation and restoration efforts by non-government organizations (*see* van Proosdij et al., 2016), or is the result of habitat compensation for construction activities, such as housing developments built by the private sector (Rahman et al., 2019). For example, CB Wetlands and Environmental Specialists Inc. along with Saint Mary's University restored 320 ha of tidal wetland habitat between 2003 and 2020 (TransCoastal Adaptations, n.d.), while Helping Nature Heal Inc. specializes in naturalizing shorelines that restore biodiversity and shoreline integrity.

Hybrid approaches that combine "hard" and "soft" engineered approaches require multidisciplinary expertise. Input from researchers, practitioners, stakeholders and the public allow scientific knowledge, local knowledge and local observations to be leveraged (*see* Box 1.1).

Case Story 1.3: Making room for wetlands: Implementation of managed dyke realignment for salt marsh restoration and climate change adaptation in Nova Scotia

The Making Room for Wetlands project (TransCoastal Adaptations, n.d.), funded by the Department of Fisheries and Oceans Coastal Restoration Fund, is developing a framework for management realignment (re-introducing tidal flow to former agricultural dykelands and the restoration of tidal wetland habitat) and testing it in a series of pilot projects to explore the viability of this framework. There is considerable variability in the ease of implementing management realignment, as illustrated through two examples.

The Belcher Street site, located on the Cornwallis River, is a mix of active and fallow agricultural lands that are protected by an ageing and eroding dyke. In exchange for improved access and a shorter dyke built to climate change standards, the Marsh Body voted in support of the management realignment project. This project restored tidal flow to 6.9 ha of wetland habitat in June 2018, reduced dyke length by over 500 m and included the use of living shoreline techniques as an alternative to traditional rock armouring for strengthening the existing foreshore. Early monitoring results indicate that the site is responding positively (*see* Figure 1.6a).

The Converse site, located at the mouth of the Nova Scotia side of the Missaguash River, included a dyke that paralleled the main river channel and was at risk of failure because of extensive erosion. Situated within a sensitive cultural and archaeological landscape—and contiguous with a national historic site—modification of the dyke had to ensure the continued protection of the Parks Canada property, as well as its cultural and archaeological features. The project involved a comprehensive archaeological resource impact assessment, and engagement with the Marsh Body and Indigenous groups, all of which influenced the final project design. Construction of the new dyke and relocation of a section of road to higher ground was completed in September 2018. Decommissioning of the approximately 1,000-m dyke and removal of the aboiteau took place in December 2018, restoring tidal flow to 15.4 ha (*see* Figure 1.6b).

Projects like these are becoming larger and more complex, requiring new approaches, processes and data to be incorporated, and involving stakeholders who have not traditionally been part of the process (Rahman et al., 2019; Sherren et al., 2019). Comprehensive monitoring, documentation and communication of the management realignment and restoration processes are essential elements for them to gain broader acceptance as viable adaptation responses.

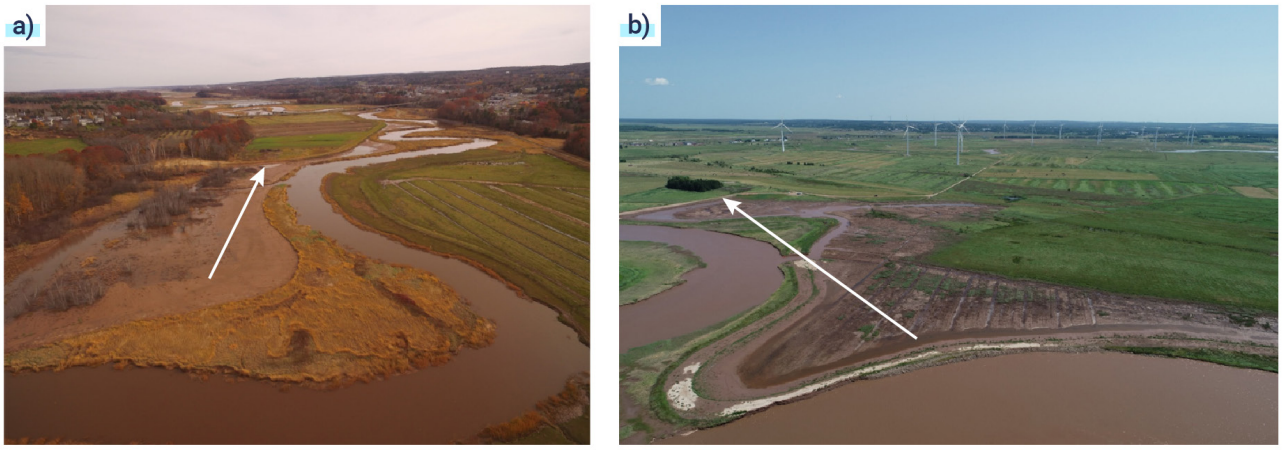

Figure 1.6: Aerial views of early-stage tidal wetland habitat recovery (brown mudflat areas) at a) Belcher Street managed realignment site, near the Cornwallis River in Nova Scotia, in September 2018 (four months post-breach); and b) Aerial view of developing intertidal habitat at the Converse managed realignment site in August 2019 (eight months post-breach). Arrows indicate location of realigned dyke. Photographs courtesy of CBWES Inc.

Case Story 1.4: Living shoreline in Halifax Regional Municipality

In Halifax, adaptation work has taken place both at a municipal level through formalized, comprehensive planning approaches and through a partnership with multiple stakeholders at St. Mary's Boat Club.

The living shoreline demonstration site at Saint Mary's Boat Club utilized a grassroots approach by establishing a partnership between the Ecology Action Centre, the Halifax Regional Municipality, Saint Mary's University and the University of Waterloo's Climate Change Adaptation Project (Miedema, 2018). This project began in 2014 and involved multiple stakeholders, including coastal professionals, students, researchers and property owners. The project included site selection, a workshop on living shorelines techniques, and finalizing of a site plan. Using biodegradable paint, participants identified locations for planting trees, shrubs, grasses and flowers at the boat club. The living shoreline was implemented in May 2015 with the help of over 70 volunteers. An additional 150 trees were planted at the boat club's demonstration project site in September 2015. Following the implementation of the project, the Ecology Action Centre has held "living shoreline clean-up parties" to assist with mulching, weeding, planting and removing debris on the living shoreline. The clean-up is an opportunity to educate the public about the importance of living shorelines.

1.2.2.5 Participatory action research and adaptation

Participatory action research projects involving researchers, stakeholders and the public have helped municipalities and local service districts develop adaptation plans and strategies (Chouinard et al., 2017, 2015, 2012, 2009, 2008, 2006; Guillemot and Aubé, 2015; Guillemot et al., 2014; Aubé and Kocyla, 2012; Guillemot and Mayrand, 2012). The advantage of such partnerships is that scientific knowledge, combined with local knowledge and observations, can help with co-constructing adaptation plans that are tailored to meet the community's needs and aspirations. In several cases, this has resulted in a shift away from traditional approaches of using "hard" engineering solutions along coastlines to encouraging the use of hybrid infrastructure solutions, or natural coastal habitats such as dunes, wetlands, and beaches. Some adaptation measures simply involved modification of physical structures, such as raising a bridge to incorporate projected sea-level rise and flood scenarios in Pointe-du-Chêne, New Brunswick, and harmonizing coastal defences in Pointe Carron, New Brunswick (Chouinard et al., 2009). Many adaptation measures utilized new scientific knowledge, such as LiDAR data in New Brunswick's Acadian Peninsula, and sea-level rise and flooding estimates for New Brunswick coastal sections. Other applied planning tools included vulnerability assessments and climate change adaptation plans (Capozi, 2020; Signer et al., 2014), new zoning and by-laws (e.g., Beaubassin-East zoning by-laws, Southeast Regional Service Commission, 2021); and education and collaboration tools, including a GIS-based community viewer (Lieske et al., 2014a). These various tools and approaches have allowed local decision-makers and adaptation actors to gain capacity and confidence, allowing them to better respond to future challenges (Rahman et al., 2019).

1.2.2.6 Retreat and relocation

Retreat and relocation are coastal adaptation strategies that have been proposed in communities located in the Acadian Peninsula, as well as along the shores of the Gulf of St. Lawrence and Baie des Chaleurs (Projet Adaptation PA, n.d.). The Province of Newfoundland and Labrador has a community relocation program that supports relocation primarily for economic reasons and government services (Government of Newfoundland and Labrador, n.d.b). Response to the relocation option has generally been poor due to the strong sense of place held by many residents and their attachment to their property (EOS Eco-Energy, 2019). For example, residents in Advocate Harbour, Nova Scotia, were not receptive to relocation as an option to address the increasing risk of storm surge flooding (EOS Eco-Energy, 2019). In some cases, refusal to consider relocation as an option creates barriers to further discussions; and measures typically target property owners and not those who rent, which can exacerbate inequities and the overall vulnerability of renters. A recent workshop in New Brunswick examined how practitioners can start conversations around the topic of relocation and explore potential challenges. Participants emphasized that relocation must be voluntary, and be informed by an understanding about risks to people's land and/or their community (New Brunswick Environmental Network, 2019). There are increasing instances of successful relocation initiatives regionally and nationally that could inform those conversations (*see* Section 1.7).

In Ferryland, Newfoundland and Labrador, the road that connects the community to the archaeological site Colony of Avalon crosses a tombolo (a sandy isthmus) that is at risk from large storm surges, especially as sea level continues to rise. Abandonment has not been an option, but existing rock revetment along the road

was rebuilt in 2010 after having been destroyed by previous storms, and required subsequent repairs and maintenance (*see* Figure 1.7a). Although maintenance of this road to serve one house would not seem appropriate (Watton, 2016, the area receives an estimated $2 million in annual tourism revenue, much of which is related to visitation of the archaeological site and the adjacent "lighthouse picnic" attraction, both of which can only be accessed using this road. However, there are some examples of abandoned coastal roads across Atlantic Canada (*see* Figure 1.7b; c).

Figure 1.7: Three examples of vulnerable coastal roads in Newfoundland and Labrador. a) Dead-end road that extends west from the community of O'Donnells, Newfoundland and Labrador, which was eroded following several storm events between 2007 and 2011. The road is no longer being maintained. b) The road that formerly followed the crest of the barachois in Clements Cove, Newfoundland and Labrador, which has now been abandoned following several wash-over events that took place between 1990 and 2010. The displaced guardrails remain. c) The breakwater that protects the tombolo road in Ferryland, Newfoundland and Labrador, was damaged frequently as a result of storm events between 1989 and 2010, and necessitated periodic reconstruction and maintenance. Photos courtesy of Norm Catto, Memorial University of Newfoundland.

In New Brunswick and Nova Scotia, foreshore marshes form the primary line of defence for dyke infrastructure, while offshore coastal ecosystems such as dunes, lagoons and sands bars provide natural protection for many coastal communities, land-use activities, and transportation and communication corridors. A recent analysis of dyke vulnerability and flooding concluded that dykes in both provinces have an increased probability of overtopping under the 2100 sea-level rise projection (van Proosdij et al., 2018). The Nova Scotia and New Brunswick Departments of Agriculture are responsible for 364 km of dykes and aboiteaux—water control structures that allow freshwater entering the dyked land to flow out through a flap gate system at low tide, which in turn does not allow salt water to enter the dyked area.

At the global scale, the practice of re-introducing tidal flow—where feasible—to former agricultural dykelands and restoring tidal wetland habitat has been identified as a viable method for adapting to current and future hazards associated with climate change (van Proosdij and Page, 2012). There is also increasing evidence that realignment of coastal protection infrastructure and restoration of tidal wetlands provide long-term and economically sensible solutions to climate change (Sherren et al., 2019; Wollenburg et al., 2018; Vuik et al., 2016; van Proosdij et al., 2014). While previous efforts to restore coastal wetlands in Atlantic Canada have focused primarily on the restoration of resilient and self-sufficient habitats (Bowron et al., 2012), the increasingly tangible impacts of climate change—combined with changing economic landscapes, regulations and land-use practices—have shifted and broadened the objectives of these projects. With limited available resources, guidance is needed to determine where and how dykes should be re-aligned to optimize ecosystem services, maximize adaptation benefits, minimize economic costs, and maintain fertile agricultural land and social, cultural and historic activities. Factors such as the degree of dyke vulnerability, the probability of failure, areas at risk and degree of urgency have helped to support decision making (van Proosdij et al., 2018). This information, combined with an analysis of return on investment, based on the specific assets protected by the dyke structures enabled the Nova Scotia Department of Agriculture to identify 64 km of dyke systems and causeways for improvements (e.g., reinforcement, realignment, salt marsh reversion, etc.) and to leverage $114 million in funding from the National Disaster Mitigation Program in 2019 to support the projects (Government of Canada, 2019). The approach of managed realignment (i.e. setting back the line of maintained defenses to a new line, which is either inland and/or at higher elevation than the original line) was considered alongside other engineering options. Regional capacity to successfully implement managed realignment is growing thorough research programs and monitoring by NGOs, academia and the private sector (Sherren et al., 2019; Wollenburg et al., 2018; Boone et al., 2017; Bowron et al., 2012). Research and collaboration are needed as projects become more complex and involve multiple stakeholders and rights holders.

The Truro area in Nova Scotia is highly prone to recurrent flooding events, with many developed areas located within the natural floodplain. In the 1600 and 1700's, Acadian settlers built up the natural riverbanks with flood-protection dykes, intended to free productive land for farming purposes. However, during periods of extreme runoff and high river flow, the dykes reduce the ability of the river and floodplain to drain to the ocean, leading to increased flood risk. Sea-level rise is directly affecting the ability of the dykes to protect against flood events from minor storm-surge events (CBCL Consulting Engineers, 2017b).

A comprehensive flood study of the Truro area has identified that realignment of the current dyke system outwards from the riverbanks—restoring a large part of the original floodplain—is a potential measure for reducing flood risk (CBCL Consulting Engineers, 2017b). The North Onslow Floodplain Restoration and Managed Realignment project brought together three Nova Scotia government departments—Department of Agriculture, Department of Transportation and Infrastructure Renewal, and Nova Scotia Environment—in a non-traditional institutional arrangement (Rahman et al., 2019) with CBWES Inc. and Saint Mary's University. The goal of the project was to design and implement a nature-based climate change adaptation strategy that will eventually restore 90 ha of tidal wetlands (Sherren et al., 2019). This study demonstrates that managed realignment can be implemented, despite complexities within the landscape and competing priorities. It also shows that gaining consensus with those who will be affected by climate change impacts takes time, and benefits from the use of effective visualization materials—including for areas that will be flooded after the dykes are removed—and locally relevant examples of the changing landscape (Sherren et al., 2019).

1.3 Climate change is exacerbating risks to health and well-being

People living in Atlantic Canada are facing significant risks to their physical and mental health and well-being from climate change. Climate change exacerbates health issues associated with existing vulnerabilities in the region, which are influenced by factors such as socioeconomic status, ethnicity, employment and living arrangements. Adaptation measures include public education, vulnerability mapping and actions to address health risks and their underlying factors.

Climate change impacts are adding to existing pressures on community health and well-being. Population vulnerabilities in Atlantic Canada are influenced by the region's physical geography, demography, economy and settlement patterns. Reducing social inequity makes people and communities more resilient and less vulnerable to many threats, including climate change. Community responses are wide-ranging and include providing education about emergency preparedness, establishing neighbourhood support networks and installing green infrastructure. Public health responses include introducing interventions to lower rates of obesity and cardiovascular disease (both are risk factors for heat-related illness and death), implementing occupational health and safety standards for outdoor workers (e.g., managing exposure to extreme heat), and delivering public education on reducing exposure to extreme heat and to ticks that can lead to Lyme disease. Institutional or corporate responses include undertaking assessments of climate change impacts on health to ensure that policies, programs and protocols support positive health outcomes.

1.3.1 Introduction

Climate change is putting pressure on the population's physical and mental health (Comeau and Nunes, 2019; Cunsolo Willox et al., 2013). Health risks for populations within the Atlantic Provinces are influenced by climate change impacts associated with the region's physical geography, climate, demography, existing socioeconomic vulnerabilities, settlement patterns, economy and community design.

1.3.2 Regional characteristics influencing health risks from climate change

1.3.2.1 Physical geography

Flooding is common in Atlantic Canadian communities and is projected to increase, affecting homes, businesses and community infrastructure located in areas at risk of flooding (e.g., Cohen et al., 2019; Greenan et al., 2019; Gunn, 2019; Julian, 2019; Kennedy, 2019; Mercer, 2019). Short-term health impacts related to flooding include physical exposure to cold and wet environments due to loss or damage to homes, as well as exposure to pathogens when sewers back up or overflow, or when flood waters contaminate wells. Longer-term impacts can include negative health outcomes resulting from mold growth and reduced indoor

air quality in unremediated and flood-damaged homes (Clayton et al., 2017). Factors such as displacement to a shelter, dealing with lost property and belongings, and returning to a damaged home—followed by cleaning, restoring and, in some cases, rebuilding—take a toll on mental health, both during and after the event (Woodhall-Melnik and Grogan, 2019; Lamond et al., 2015; Carroll et al., 2009). This can be further exacerbated by the possibility of re-flooding in the future, especially in cases where rebuilding takes place in the original flood-prone location. Riverine flooding and sea-level rise can make lowlands uninhabitable and forced relocation diminishes the sense of place, resulting in negative consequences for mental health (Government of Canada, 2020a; Ohl and Tapsell, 2000).

1.3.2.2 Health impacts related to extreme weather

Atlantic Canada is geographically and climatically complex, and human health impacts related to extreme weather events, many of which are expected to increase (e.g., storm events, heat waves) (Bush and Lemmen, 2019; Roy and Huard, 2016), are of particular concern. Severe winter storms can leave people without heating in their homes and without access to water when pumps fail due to the loss of electricity. Build-up of ice on the roads can make travel nearly impossible, leaving many people isolated and low on supplies. This was the case in January 2017, when an ice storm paralyzed a large portion of New Brunswick. More than one third of NB Power's customers were without electricity for more than 10 days in some parts of the province, causing many emergencies. Without electricity, some homes had no heat and no access to water from their private well; at the peak, 133,000 customers (equating to over 300,000 people) were without power, which is a particular concern for vulnerable communities with few resources (Wagner, 2017). Some people tried to heat their homes using alternative methods, including generators without proper ventilation. Tragically, two people died and 49 people became ill from carbon monoxide poisoning (Wagner, 2017).

While coastal Atlantic Canada benefits from the moderating effects of the ocean, inland areas experience more extreme hot temperatures, making heat waves more likely. Table 1.3 provides examples of heat wave projections for some Nova Scotia communities and for Fredericton, New Brunswick, which show a doubling or tripling of the number of days above 30°C in the near term (2020s) and a four- to six-fold or more increase in the mid-term (2050s) to the long term (2080s) (Zhang et al. 2019; Roy and Huard, 2016; Richards and Daigle, 2011).

Table 1.3: Examples of the annual number of observed and mean projected days above 30°C in communities within Nova Scotia and New Brunswick

	NUMBER OF DAYS ABOVE 30°C PER YEAR			
	1980s (actual)	**2020s (projected)**	**2050s (projected)**	**2080s (projected)**
Fredericton, N.B. (Saint John River, inland)	9	16	31	53
Kentville, N.S. (Cornwallis Valley, inland)	3.5	8.4	15.4	24.9
Greenwood, N.S. (Annapolis Valley, inland)	6	11.3	19	32.7
Liverpool-Milton, N.S. (Mersey River, 5 km inland)	6.2	11.8	20.4	29.9
Bridgewater, N.S. (La Have River, 15 km inland)	5.8	12.6	21.6	31.4
Charlottetown, P.E.I. (climate station A)	0.7	2.2	5.3	12.3

Projections by Richards and Daigle (2011) were developed from models available for the IPCC AR5 high emissions scenario for New Brunswick, and AR4 medium-high to high emissions scenarios A1B and A2 for the others. Sources: Richards and Daigle, 2011 (Nova Scotia and Prince Edward Island data); Roy and Huard, 2016 (New Brunswick data).

Community and individual factors affect vulnerability to extreme heat exposure. Risk factors for rural areas in Atlantic Canada include an ageing population (i.e., seniors tend to be more at risk to heat-related health impacts); a large proportion of outdoor workers in agriculture, fisheries, forestry and mining (14% of the region's labour force is employed by these industries; Statistics Canada, 2020b); homeless populations; poorly insulated homes, which are common in older communities; and older community infrastructure in general, which is more susceptible to disruption or damage under extreme heat (e.g., Comeau and Nunes 2019; *see* also Rural and Remote Communities chapter and Cities and Towns chapter of the National Issues Report).

1.3.2.3 Socioeconomic vulnerability and health

Health outcomes are often linked with socioeconomic vulnerability, which is influenced by factors such as age, income, reliance on government transfer payments, being a new Canadian, language skills, level of education and living arrangement (e.g., single-parent family, senior citizen living alone) (Government of Canada, 2020b). Socioeconomic vulnerability is a major factor in how individuals and groups experience climate change (Preston et al., 2011; Cutter et al., 2008; Cutter and Finch, 2008) and what this experience means for personal and community health and well-being. It is apparent, for example, that older people are at increased risk to adverse health outcomes related to climate change (e.g., in Nova Scotia, Manuel et al., 2015), and thus social vulnerability is an important element of comprehensive risk assessment processes.

1.3.3 Adaptation approaches

Several adaptation initiatives in Atlantic Canada directly or indirectly address the health and well-being of residents to reduce the risks of a changing climate. The following examples highlight different approaches and factors in achieving successful outcomes.

1.3.3.1 Response to the 2017 ice storm in New Brunswick

The impacts of the January 2017 ice storm in rural New Brunswick highlighted the previously documented relationships between environment, community and health (Gillingham et al., 2016). The response to these impacts drew attention to the complexity of provincial government, local government and civil society systems and structures, informal networks, and individual reserves that people draw upon in responding to an emergency of this magnitude. Interdisciplinary analysis of responses to the storm, using a socioecological framework and the social determinants of health, emphasized the importance of environmental, governance and social factors with respect to the vulnerability and resilience of individuals and communities (*see* Case Story 1.5; Cunsolo Willox et al., 2013; Webb et al., 2010). It also showed how social actors in a region affected by extreme weather succeeded in strengthening the social capital and overall resilience of the community.

Case Story 1.5: Responding to the ice storm crisis in the Acadian Peninsula, New Brunswick

In addition to causing significant economic losses, extreme weather events have been detrimental to the well-being of certain communities and have highlighted situations of poverty (Wagner, 2017; Government of New Brunswick, 2016). The health and economic profile of the population living within the Acadian Peninsula (*see* Figure 1.8) is lower than the Canadian average (Vitalité Health Network, 2017). In the face of the ice storm in 2017 (*see* Figure 1.9), social capital (i.e., the presence of a solid network or belonging to a group (Ostrom, 2008)) contributed to the resiliency of residents during the crisis. During emergencies, social capital

can grow as new friendships develop and as young people become more engaged in their communities and become interested in volunteering.

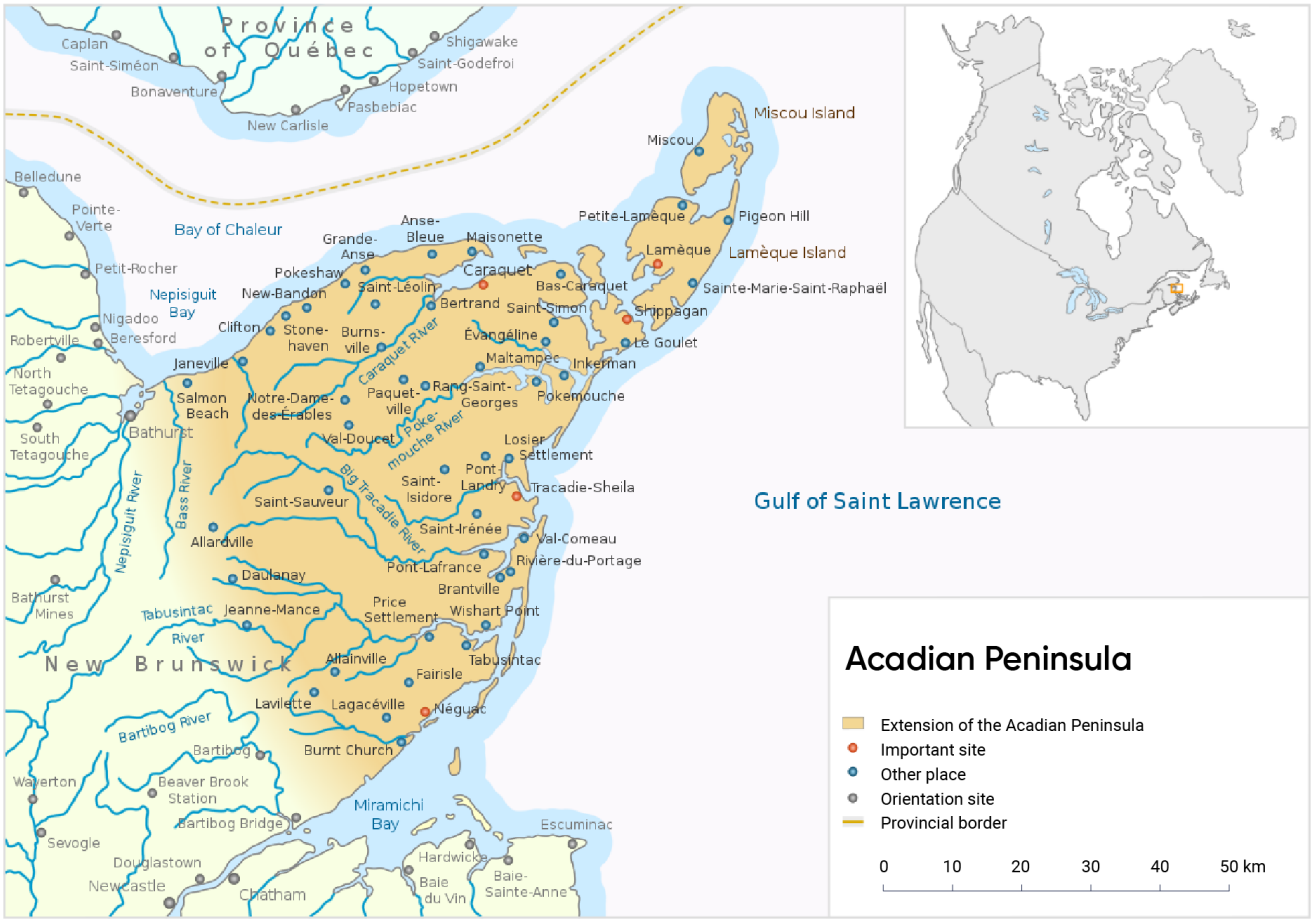

Figure 1.8: The Acadian Peninsula, northeastern New Brunswick. Source: Image (Map) made by Klaus M. (Mi'kmaq), Germany, retrieved from Wikipedia, 2020.

Figure 1.9: Damage caused by the 2017 ice storm in the Acadian Peninsula. Source: The Canadian Press/Diane Doiron

It is important that initiatives to strengthen the social capital of communities (Noblet et al., 2016) and to help improve the health of populations (Chriest and Niles, 2018) consider cumulative impacts and ecosystem approaches to health (Charron, 2012). Other initiatives, such as *Imaginons la Péninsule acadienne autrement*, are leveraging the economic and social potential of renewable energies and food self-sufficiency to make the Acadian Peninsula a more resilient territory. Such inter-sectoral initiatives can serve as catalysts to address social and economic inequalities. A collective, solidarity-based approach has the potential to spur innovative, comprehensive solutions to the climate change risks (Parkes et al., 2016; Prainsack and Buyx, 2016).

1.3.3.2 Vulnerability maps

A key tool for addressing vulnerability to heat-related health impacts includes the creation of vulnerability maps for municipal decision making and analysis of physical design, policy, planning and programming interventions to reduce vulnerability (*see* Case Story 1.6). For example, vulnerability maps can identify where there are large populations of seniors, who are at increased risk to heat waves, and can help to target public outreach efforts to enhance their resilience, such as by avoiding isolation, staying healthy and hydrated, improving shade with awnings or tree planting, and acquiring air-conditioning (e.g., Gower et al. 2011). It is increasingly important for adaptation initiatives to consider the needs of senior citizens, and to involve them in planning and implementing actions.

Case Story 1.6: Mapping heat vulnerability in Middleton, Nova Scotia

Middleton is a small town in Nova Scotia's Annapolis Valley. It is located within one of the warmest areas of Atlantic Canada, and is well sheltered from maritime influences. Like many towns in the Annapolis Valley, its economy historically relied heavily on agriculture, although tourism and the service sectors now dominate. Middleton's infrastructure is older, especially its housing stock and historic commercial district. For example, 76% of the housing stock was built before 1980; 46% was constructed before 1960 (Statistics Canada, 2016). The historic commercial centre was developed between the mid-19th and early 20th centuries.

A Heat Stress Pilot Study of the town (Manuel et al., 2016a) produced a map showing that less than 5% of the town's surface area is considered to be a "cool" environment (e.g., one that provides shade) and is typically characterized by remnant pockets of natural vegetation (*see* Figure 1.10). Twenty percent is considered to be a "hot" environment (e.g., exposed to the sun), with the main contributors being asphalt roadways and parking lots located in the commercial area along Main Street, where there are exposed south-facing slopes and no shade trees.

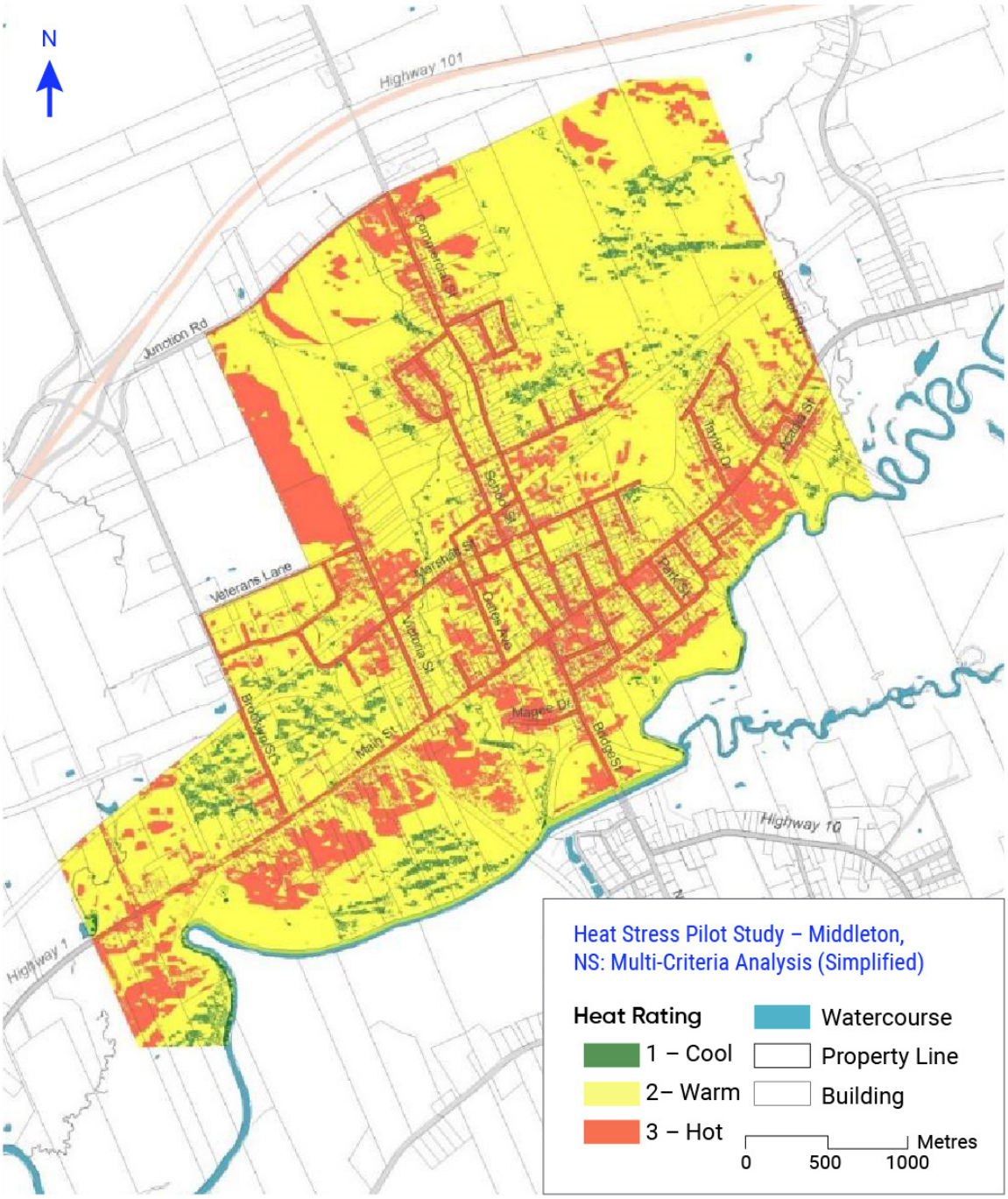

Figure 1.10: Map of attributes in natural and built environments within Middleton, Nova Scotia and their cooling or heating influence. Attributes considered include water regime, aspect, air circulation and surface materials. Source: Manuel et. al, 2016a.

Further analysis considered linkages with vulnerability (*see* Figure 1.11), as well as opportunities for improvement. Particularly vulnerable areas include the oldest residences, the Veterans Memorial Hospital and

Veterans Long-Term Care Unit (both have air conditioning, but are located in exposed areas with very little shade), and the Magee Drive housing development for seniors and persons with disabilities. Many elderly people—who are generally at greater risk of heat-related illness—live in these residences and facilities. While the town does not have a cooling centre program, it does have large, public and quasi-public facilities with climate control systems that could be used as cooling centres, if needed. The town also has an outdoor public pool and a splash pad, and many homeowners have private pools. The trees along the riverbanks also provide a cool environment, and some streets have a tree canopy.

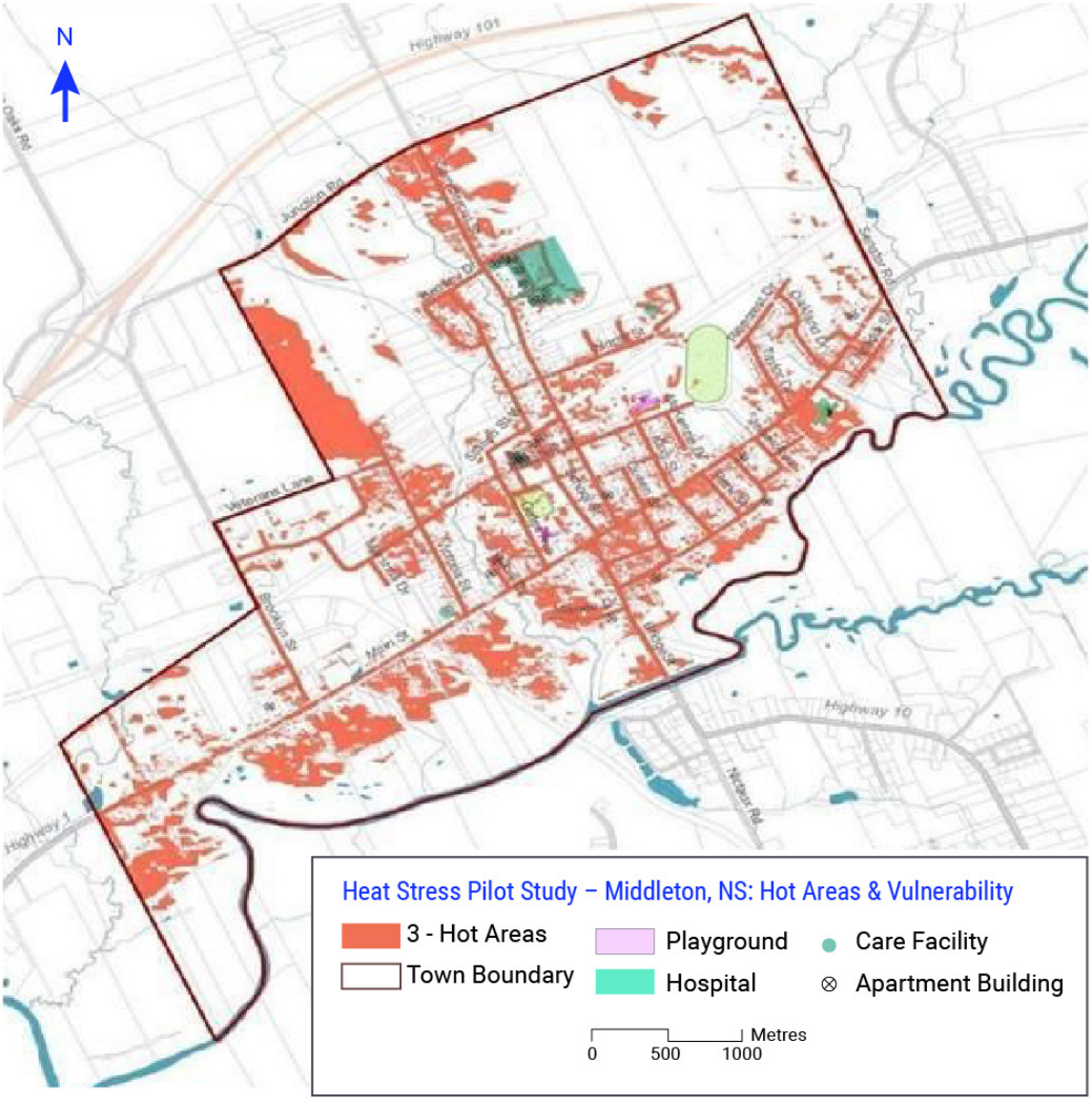

Figure 1.11: Location of facilities relative to "hot" areas in Middleton, Nova Scotia. Some facilities support vulnerable populations, including the elderly or people with long-term care needs. Other areas are spaces for outdoor recreation, with exposure to sun and heat. Source: Manuel et al. 2016a.

Physical design interventions to reduce heat exposure include installing shade structures—such as shade-providing trees, awnings, tents and gazebos—in the exposed commercial core, parks, playgrounds and parking lots (Forkes et al., 2010).

1.3.3.3 Understanding social vulnerability

Reducing social inequity makes people and communities more resilient and less vulnerable to many threats, including climate change. Many people and groups are particularly vulnerable to climate change, as it further stresses existing conditions and precarious situations. By better understanding the patterns of social vulnerability in relation to climate change hazards that can occur in an area, provincial and local governments and NGOs can work to reduce the impact of the hazard on vulnerable people and communities (*see* Case Story 1.7; Manuel et al., 2016a).

Atlantic Canada has the oldest and most rural population in the country (Government of Nova Scotia, 2017; Statistics Canada, 2015b). Ageing increases the likelihood of other factors—such as respiratory and cardiovascular disease—that can make individuals, and an overall population, more vulnerable to climate change hazards and impacts (Carter et al., 2016; Kenny et al., 2010; Haines et al., 2006). These conditions put people at greater risk from climate change hazards, such as poorer air quality and extreme heat, and can lead to greater reliance on emergency services during events such as storms or heat waves. However, access to emergency services during storms could be compromised due to impacts on roads in flood-prone areas. Older people also tend to have lower incomes, which limits their ability to adequately prepare for and recover from climate emergencies (Statistics Canada, 2019e). Rurality further increases the risk, considering the limited health services in rural areas and the long distances that people often need to travel to access them (*see* Rural and Remote Communities chapter of the National Issues Report).

Case Story 1.7: Social vulnerability mapping in Nova Scotia as a tool for informing adaptation

Social Vulnerability Mapping is a high-level planning tool for informing emergency and climate change adaptation planning and response. By understanding patterns of social vulnerability in relation to anticipated climate change hazards, such as coastal flooding, a community can take action to limit impacts on vulnerable populations. Maps of social vulnerability for Nova Scotia (Manuel et al., 2016b) were produced using a Social Vulnerability Index (SVI; adapted from Cutter et al., 2003), which draws from Census and National Household Survey data (Statistics Canada, 2011) to derive statistics related to health determinants for each of Statistics Canada's Dissemination Areas (DAs) across the province (*see* Figure 1.12).

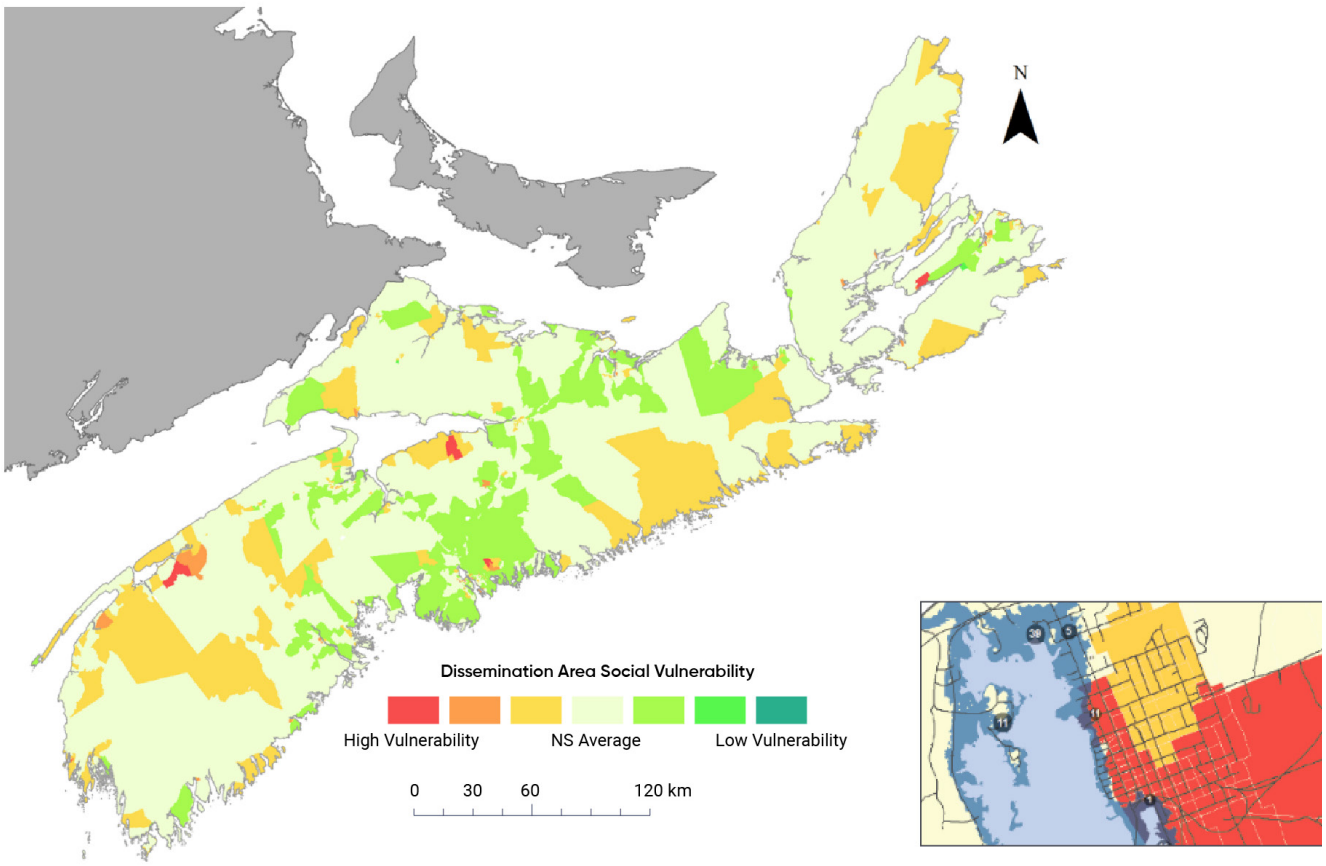

Figure 1.12: Map of Dissemination Areas in Nova Scotia showing levels of social vulnerability, based on a Social Vulnerability Index (SVI). The inset map from a coastal community illustrates the integration of the SVI mapping with a proxy representation (i.e., the dark blue overlay) of projected worst-case relative sea-level rise and storm-surge flooding to 2100. The inset map also shows a count of residential buildings and the distribution of roads within the proxy flood area. Sources: Government of Nova Scotia, n.d.; Richards and Daigle, 2011; Statistics Canada, 2011.

The SVI visualization was layered over a proxy representation of different worst-case scenarios for projected coastal flooding up to 2100. The analysis prepared by Richards and Daigle (2011) suggests that the projected 2100 worst-case flood extents would not exceed an elevation of 5 metres along the Atlantic and Northumberland coasts or 10 metres along the Bay of Fundy, with the exception of the upper reaches of Cobequid Bay (adjusted from chart datum to CGVD28; Richards and Daigle, 2011). To delineate worst-case 5- and 10-metre flood elevations proxies for policy planning purposes, researchers worked with the Applied Geomatics Research Group of the Nova Scotia Community College to develop continuous contour elevations for the coastal areas of Nova Scotia using the best available elevation information (Manuel et al. 2016b).

Analysis of the SVI data alone revealed that 53% of coastal DAs in Nova Scotia (i.e., DAs that have a coastline

and that will, therefore, experience coastal flooding) have vulnerability levels that are within the provincial average; 23% have lower-than-average vulnerability levels; and 24% have greater-than-average vulnerability levels. The integrated mapping also showed that 19,795 residential buildings lie within the extreme flood zones—based on the worst-case scenarios for projected coastal flooding up to 2100—and 4,333 of these are located in coastal DAs that have greater-than-average levels of social vulnerability.

Fact sheets were created for all Nova Scotia municipalities, including a map of each municipality showing the SVI visualization, SVI statistics for each DA within the municipality and an overall SVI statistic for the municipality. The fact sheets for the coastal municipalities also included information about the relationship between social vulnerability and the proxy flood zones within the municipality, and the number of residences located within the proxy flood zones. Municipalities and the provincial government can use the Social Vulnerability Maps and fact sheets to identify locations for site-specific examination and to inform emergency preparedness.

1.4 Indigenous experiences inform adaptation in Atlantic Canada

The Mi'kmaq, Wolastoqiyik and Peskotomuhkati Nations of the Wabanaki Confederacy have occupied the Maritimes since time immemorial and have adapted to changes in climate and the environment over countless generations. Partnerships with, and leadership by, local Indigenous peoples are vital to ensuring that the knowledge, perspectives and experiences that they hold from living on the land, inform adaptation in their communities and in the region.

The storytelling culture of the Indigenous peoples in Atlantic Canada has preserved cautionary tales of life in a climate and environment that is changing at a pace dictated by Mother Earth. For instance, historically, Wabanaki peoples had adapted their harvesting practices to cope with the periods of extreme cold, fluctuating climate patterns and short growing seasons associated with the Little Ice Age. The Indigenous people of the Saint John River—the Wolastoqey—successfully cultivated maize by utilizing their knowledge of local microclimates and early harvesting strategies. Wolastoqey were able to manage a broad array of plants as a result of the accumulated knowledge of flood regimes and soil conditions over centuries of living along the Saint John River. However, the arrival of the Industrial age and the subsequent release of greenhouse gases into the atmosphere have accelerated climate change to the point that traditional Indigenous adaptation philosophies are being forced to change and address the new reality.

1.4.1 Introduction

Many Indigenous communities, including the Mi'kmaq communities of Esgenoopetitj and LnuiMenikuk, are strategically located at the mouths of rivers because these areas are biologically productive. They are located on New Brunswick's eastern shore and the waters of Northumberland Strait, where geologic subsidence is resulting in most coastlines gradually submerging at a rate of several millimeters per year (Zhai et al., 2015). These communities have adapted to climatic and environmental changes since time immemorial. Before European colonization, they moved their seasonal settlements to new locations year after year. When the Crown imposed the reserve system on First Nations people in the early 1800s, the community was no longer free to move with the changing environment and was confined to a land base with a fixed backstop, unable to retreat from the eroding shoreline. Today, the land base of these communities continues to diminish, while sea-level rise is increasing and coastal erosion is accelerating due to reduced winter sea-ice cover and more severe storm surges (Greenan et al., 2019; Savard et al., 2016). As populations grow, they are being squeezed (*see* Box 1.1). Communities are assessing future climate change impacts and adaptation approaches, while considering how to develop economic opportunities to meet the needs of their growing populations.

Box 1.1: Diminished reserve lands leave First Nations with nowhere to grow

The reserve system has become a shrinking trap, where community land parcels have been reduced while population size has grown. The establishment of the first reserve occurred in 1782, when the government set aside a "License of Occupation" (forerunner to today's First Nation Reserve System). For example, in New Brunswick, "Twenty thousand acres on the Northwest Branch of the Miramichi River for (Chief) John Julian and his tribe" (Cuthbertson, 2015, p. 7). This was also the year when the Nova Scotia colonial government (New Brunswick separated from Nova Scotia in 1784) first allowed land grants to Loyalists. Over the next few decades, the New Brunswick colonial government, as dictated from London, set aside more large swaths of land as Licences of Occupation for the Mi'kmaq and Wolastoqiyik Nations. Over the next few decades, these reserve lands shrunk, as government officials (Indian Agents) sold off the best tracts of reserve lands to incoming European emigrants. Many reserve lands were drastically reduced: Buctouche, established in 1798, originally 40,940 acres, reduced to 4,665 acres in 1820, currently 345 acres; Tobique, established in 1801, originally 16,000 acres, currently 6,225 acres; Richibucto (Elsipogtog), established in 1802, originally 51,200 acres, reduced to 5,720 acres in 1820, currently 3,148 acres (GeoNB 2021).

1.4.2 Risks to Indigenous communities and culture

The coastal and inland erosion of archaeological sites is an ongoing issue for Indigenous peoples, with serious political and cultural implications. The loss of archaeological evidence of Indigenous occupation on these lands has potential implications for Indigenous title, land, water and resource claims. Coastal erosion has destroyed archaeological sites and is threatening many existing sites. For example, in Kouchibouguac

National Park (KNP), located on the Northumberland Strait about halfway between Esgenoopetitj and LnuiMenikuk, archaeologists have identified a number of archaeological sites along the coast and tidal rivers that are subject to coastal erosion (*see* Figure 1.13). Damage to key resources arises from many causes, with climate change often amplifying negative impacts. The loss of traditional plants and food sources due to raw sewage, fuels and chemicals leaking into the rivers during flooding events in traditional harvesting areas can have negative effects on Indigenous culture, socioeconomic circumstances, health and well-being. For instance, the New Brunswick Emergency Measures Organization and Department of Health have issued warnings in the past decade that fiddleheads growing in flooded areas may be contaminated and unfit to eat (Fowler, 2018). Fiddleheads are part of a traditional spring diet for Indigenous peoples to help cleanse the body, and they are also a source of income.

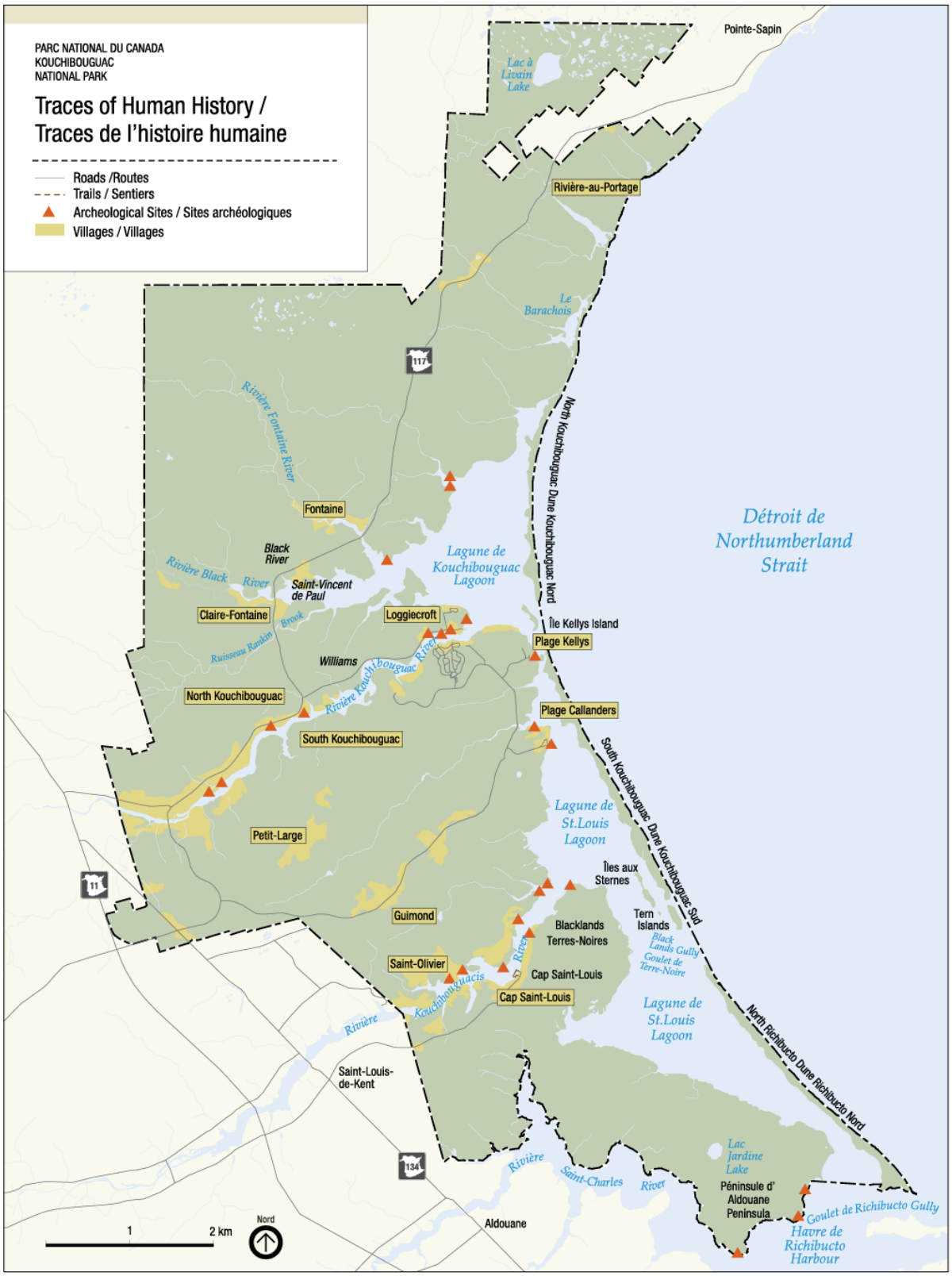

Figure 1.13: Kouchibouguac Archaeological Sites Map. Source: Parks Canada, 2020.

The Mi'gmaq community at Ugpi'ganjig, located at the mouth of Eel River on New Brunswick's Chaleur Bay is an example of a People whose traditional plant and food sources have been affected by contamination. In 1963, the New Brunswick government constructed a dam on Eel River. The primary objective of this project was to establish a water supply for major industries in the area. Secondary objectives were to establish a long-term solution to fish passage and to improve habitat for soft-shelled clams and other shellfish (Government of New Brunswick, n.d.b). In fact, the dam resulted in the contamination of clam beds and the near collapse of salmon, eel and smelt fisheries, all traditional foods for the Mi'gmaq of Ugpi'ganjig. Changes in sediment distribution caused the destruction of sand bars, and increased erosion led to the loss of 60 acres of land, including 15 acres of beachfront property (Eel River Bar First Nation, n.d.a). This left the community vulnerable to the extreme events of storms and high tides (Eel River Bar First Nation, n.d.). One such extreme event occurred on December 6, 2010, when a storm and tidal surge flooded the community, resulting in the evacuation of 10 homes on the First Nation and caused $1,725,000 in damages (Government of New Brunswick, n.d.c). The community responded by reconstructing homes on raised terraces, erecting a concrete sea-wall and purchasing additional land to house its growing population.

Lennox Island, located within Malpeque Bay on the north shore of Prince Edward Island, is home to Lennox Island Mi'kmaq First Nation, which experienced severe flooding from sea-level rise and reduced seasonal sea-ice cover. Most of the Island lies one or two metres above sea level, making it vulnerable to flooding and storm surges (Bissett, 2016). Its sand and sandstone composition makes it highly susceptible to coastal erosion. Rising sea levels and coastal erosion have already reduced the size of the Island from 1,520 acres in 1880 to 1,240 acres in 2010 (Bissett, 2016). Sacred burial grounds, located on a nearby island, have started washing away (Kassam, 2017), as have archaeological records, cultural artifacts and remains of ancestors (*see* Case Story 1.8; Kassam, 2017; CBC News, 2016; Mitchell, 2015). In addition to losing part of its history and knowledge, the community is facing risks to its Pow Wow grounds, medicinal plant sites, critical infrastructure and residential properties (Fenech and Arnold, 2018).

Case Story 1.8: Confronting rising seas on Lennox Island, Prince Edward Island

The Mi'kmaq Confederacy of Prince Edward Island (MCPEI), which represents the province's Indigenous peoples, has commissioned a number of scientific studies on climate change impacts for the local Indigenous communities (Mitchell, 2015). Chief Matilda Ramjattan of Lennox Island has welcomed this work, which has helped the community design its adaptation approach (Mitchell, 2015). A key element of the work has been the use of visualization tools, such as Coastal Impacts Visualization Environment (CLIVE), for examining potential climate change impacts (*see* Figure 1.14). By utilizing 3D game technology, users can "fly" around the community and select different erosion and sea-level rise scenarios to observe changes in vulnerability over time (University of Prince Edward Island Climate Research Lab, 2020). This enabled community members and leaders to use highly detailed scientific information in an intuitive and visual way. Other additional adaptation initiatives (*see* Table 1.4) also informed the consideration of different adaptation options.

Figure 1.14: Screenshots of Lennox Island a) under present-day conditions, b) under a 3-m sea-level rise and/or storm surge scenario, and c) with 1968 coastline (red) and 2100 coastline, based on the annual coastal change rates between 1968 and 2010 (blue). Source: University of Prince Edward Island Climate Research Lab, 2020.

Table 1.4: Adaptation work commissioned by the Mi'kmaq Confederacy of Prince Edward Island

ADAPTATION WORK	DESCRIPTION
The use of oral histories in identifying climate trends at the Mi'kmaq Confederacy of Prince Edward Island *	Indigenous and local knowledge and observations, in combination with instrumental data recorded by a climate station, were used to better understand regional climate change.
Cultural values in the coastal zone*	Values representing Mi'kmaq cultural landscape sites—produced by members of Lennox Island and Abegweit Bands—were mapped using Geographic Information Systems (GIS) technology. These maps visualized the locations of the sites in relation to areas of coastal vulnerability, and assisted band leaders in selecting and prioritizing adaptation programs.
Coastal engineering assessment: Impacts of climate change and sea-level rise	Information on the frequency of flood occurrence, both now and in the future, and projected flood levels were explored. Focusing on key areas of concern, this work described adaptation strategies and specific construction works to cope with coastal flooding and coastal erosion.

ADAPTATION WORK	DESCRIPTION
Lennox Island erosion survey and assessment*	Imagery of the coastline captured by RPAS (Remotely Piloted Aircraft System) was made available for year-to-year comparison, which allows for the quantification of impacts from coastal erosion, sea-level rise and storm surges. On-the-ground measurements were also used.
Community training on small unmanned aerial vehicles (RPAS)*	RPAS training was provided to community members to promote an improved understanding of the community's risk to climate change and to enhance commercial opportunities. The seven-day course trained attendees on the safe operation of RPAS in a marine coastal environment.

*This work benefited from community partnership and involvement.
Source: Fenech and Arnold, 2018.

In response to the clear risks presented by climate change, the band has acquired property on mainland Prince Edward Island, should homes need to be relocated due to coastal flooding and/or erosion (Bissett, 2016). Chief Ramjattan and council members considered how the relocation process could be implemented, which parcels of land could be suitable and whether further investments in blueberry fields and forestry on Lennox Island would be prudent (Mitchell, 2015). The Government of Prince Edward Island is working to relocate and preserve Mi'kmaq artifacts as quickly as possible before they are claimed by the sea (Mitchell, 2015).

The community and its leaders continue to partner with and participate in scientific work informing adaptation planning and implementation. Community involvement has elevated the impact of the adaptation work thus far—from raising the level of awareness among community members to designing adaptation approaches that suit the local context. "We are an adaptable and resilient people, and we will figure this out," says Chief Ramjattan (Mitchell, 2015). Her focus lies beyond addressing immediate risks and solutions. "I have to think about generations in the future," she commented (Kassam, 2017).

1.4.3 Adaptation in Indigenous communities

The Indigenous peoples of Atlantic Canada have experienced climate variability such as glaciation, mini ice ages, warm periods and subsequent changes in the environment, and have learned to adapt to changing conditions. The Oxbow site at Metepenagiag First Nation on the Northwest Miramichi River shows proof

of continuous occupation for the past 3,000 years (Allen, 2005). Throughout those years, the climate has naturally fluctuated, and Indigenous peoples have responded by adapting. Archaeological excavations of hearth areas at the site show that the most common fish bones found were sturgeon, although this species is rarely seen today in the Red Bank area (Allen, 2005). Through the 19th and 20th centuries, Atlantic salmon were the dominant large fish species in the Miramichi River—in fact, the Miramichi was world-famous for its salmon, and many important people came to the Miramichi Valley to angle for this "King of Fishes." Up until the 1970s, Atlantic salmon were harvested as a food fishery by the Metepenagiag Mi'kmaq community. The salmon fishery started its steep decline in the late 20th century. The hotter, drier summers experienced over the last few years have further stressed the remaining salmon (*see* Atlantic Salmon Federation, 2018). The once-thriving sports tourism industry created by salmon angling has diminished to the point that sports anglers must now release the salmon alive. Over the past decade, striped bass have increased dramatically and are replacing Atlantic salmon as the dominant sport fishery (Johnson, 2021).

The community of LnuiMenikuk is adapting to climate change challenges. While their current reserve land is dealing with relative sea level rise, community members are continuing the Mi'kmaq tradition of harvesting from the sea by developing a commercial oyster cultivation industry. This is a challenging industry to develop considering the changing climate and more violent storms. The Indian Island Aquaculture Development Corporation has been growing high quality choice and cocktail oysters since 2007 (Indian Island First Nation, 2015). This is an example where the establishment of a marine protected conservation area could provide a nursery for the oysters.

1.4.4 Indigenous knowledge systems

"Two Eyed Seeing" is a way of learning first proposed by Elder Albert Marshall from the Eskasoni Mi'kmaq Nation. "Two-Eyed Seeing" is learning to see from one eye with the strengths of Indigenous knowledge and ways of knowing, and from the other eye with the strengths of Western (and/or scientific) knowledge and ways of knowing, while learning to use both of these eyes together for the benefit of all (*see* Box 1.2 ; Elder Dr. Albert Marshall, cited in Reid et al., 2020). This concept is widely used by Mi'gmaq Nation groups when conducting research where community knowledge from Elders is sought and used with Western knowledge in the decision-making process. Examples include the Eel River Bar Sea Level Rise study, where the community used a "Two-Eyed Seeing" approach (Gillis, 2020). Mi'gmawe'lTplu'taqnn Inc., which represents nine New Brunswick Mi'gmaq communities, also routinely uses knowledge from its community members in assessing the impact of resource development projects in its territories.

Box 1.2: Two-Eyed Seeing

Two-Eyed Seeing, a term coined by Mi'kmaq Elder Albert Marshall, refers to the concept of learning to see with one eye the strengths of Indigenous knowledge systems and ways of knowing, and with the other eye, the strengths of Western knowledge systems and ways of knowing (Bartlett, 2017). This requires valuing and

honouring Indigenous voices and Indigenous ways of knowing, as well as changing the way that work and research are conducted (Peltier, 2018). Through the mindful use of these two points of view, expertise from different disciplines and knowledge systems can make complementary contributions for the benefit of all (Bartlett, 2017). This allows questions to be framed in new ways, priorities to be ranked differently, and people to engage with each other on different terms (Peltier, 2018). Efforts have been made to apply Two-Eyed Seeing in climate change adaptation within Atlantic Canada. For example, the Mi'kmaq Confederacy of Prince Edward Island practices Two-Eyed Seeing in the design and execution of its adaptation projects (*see* Case Story 1.9).

Case Story 1.9: Applying Two-Eyed Seeing to Adaptation in New Brunswick

In New Brunswick, Mi'gmawe'lTplu'taqnn Inc. (MTI) is "a L'nuey leadership body that protects our people by asserting and implementing our Inherent, Aboriginal and Treaty Rights throughout Mi'gma'gi" (Mi'gmawe'lTplu'aqnn Inc., n.d.). In a practical example of Etuaptmumk, or Two-Eyed Seeing, MTI asserts Mi'gmaq treaty rights by conducting Indigenous Knowledge Studies to determine the impact that infrastructure and resource development projects will have on its community members. The Organization's leadership (the Chiefs) developed a New Brunswick Mi'gmaq Indigenous Knowledge Study Guide as a framework to conduct these studies. The first study was for the proposed Energy East pipeline in 2016. Since the first project, MTI has conducted Indigenous Knowledge Studies for the following: provincial park expansions; peat extraction operations; mines; energy projects, such as wind turbines or solar farms; infrastructure projects, such as bridge construction and harbour dredging; and heavy industrial projects, such as an iron manufacturing facility or smelter decommissioning. These studies are funded by the project's proponent. For private industry, the Indigenous Knowledge Study is usually part of the Environmental Impact Assessment approval process. For federal and provincial government projects, the study is funded through nation-to-nation contribution agreements. Interviews with community knowledge holders are conducted using a standardized script and GIS technology to capture and catalogue geographic information. Knowledge Holders are asked about past and current land use and environmental observations. Responses are catalogued as either "Land Use" or "Mi'gmaq Environmental Knowledge". As a result of these projects, MTI has compiled a geodatabase of community knowledge recognizing environmental changes that have occurred over the past few generations. This same geodatabase serves as a benchmark for environmental studies going forward (Johnson, 2021).

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 pre-commercial 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).

1.6 Building adaptive capacity will strengthen resilience

Adaptive capacity in Atlantic Canada is often constrained by limited human and financial resources. Partnerships and collaboration between different stakeholders—including governments, NGOs, academia and the private sector—are important for driving adaptation in the region. Outreach, public education and effective communication are key for building adaptive capacity in Atlantic Canada.

Adaptive capacity is the ability of individuals, institutions and systems to adapt and thrive to changing conditions. Unfortunately, many institutions in Atlantic Canada—including governments and small communities in rural areas—have limited capacity to engage in climate change adaptation. Access to economic resources, social inequities and other factors can also influence adaptive capacity. Structured processes that identify current or baseline capacity help institutions and systems build their capacity to adapt together.

1.6.1 Introduction

Adaptation to complex challenges, such as climate change, often requires a variety of capacities. This can involve a blend of technical, scientific knowledge and Indigenous knowledge (e.g., climate information, risk assessments, tools for adaptation planning) as well as social and cultural factors (e.g., stakeholder commitment and engagement, leadership, the ability to share information freely, support for risk taking) as well as the financial resources to be able to implement adaptation measures (Forth, 2019; Federation of Canadian Municipalities, 2018; Manuel et al., 2015; Vogel, 2015). These capacities help make adaptation action and success more likely and are considered essential to adaptation. However, enhancing these capacities can also help with a variety of challenges beyond adaptation. As many adaptation efforts are complex and involve different levels of governance, efforts to systematically and intentionally strengthen

adaptive capacity in a structured and deliberate manner are often a precursor to effective climate change adaptation (Organisation for Economic Co-operation and Development, 2019; Sherren et al., 2019; Federation of Canadian Municipalities, 2017). Many consider the capacity to adapt as being vested in several organizations or a system, rather than in just one organization, and believe that participation in a network of institutions can collectively build adaptive capacity (Rahman et al., 2019). Investing in adaptive capacity can yield multiple benefits, as institutions and communities with stronger adaptive capacity are better able to thrive in the face of multiple threats and changes, in addition to climate change (Krawchenko et al., 2016; Manuel et al., 2015; Janowitz et al., 2013).

The success of community-based capacity building is linked to awareness raising, outreach, community meetings and other educational programs, which disseminate knowledge about climate change risks and adaptation options, and lead to enhanced social resilience (*see* Box 1.3; Noble et al., 2014). Disseminating complex scientific information on climate change to the public can be challenging, and specialized tools to aid communication are often needed to effectively raise public awareness. Strategic research partnerships can facilitate knowledge sharing and provide access to data and advanced technological resources.

Box 1.3: Building adaptive capacity at the local level

Building adaptive capacity at the community level requires ongoing public education, communication and outreach. Local NGOs often operate using a bottom-up approach, with support from the municipal or provincial government or other funding agencies. In Atlantic Canada, these collaborations have produced vulnerability assessments and adaptation plans, and have implemented actions (e.g., EOS Eco-Energy 2019, 2017, 2013). While public outreach can require significant resources and time, such efforts within communities have led to improved public awareness and increased support for adaptation initiatives and policy development (e.g., Marlin and Wooley-Berry, 2017). These efforts in turn have led to more effective collaboration on climate change adaptation initiatives in the region.

It is also recognized that working with and across multiple stakeholder groups has immediate benefits, including developing joint goals, sharing resources and building relationships among all stakeholders (Feist et al., 2020; Plummer et al., 2017). As a result, collaboration contributes to better outcomes, such as a greater appreciation of climate change issues, benefits to the environment, social learning, and improved decision making and governance (*see* Case Story 1.11).

Case Story 1.11: Characteristics of effective collaboration

Three adaptation initiatives undertaken in New Brunswick—in the Saint John River Valley, Charlotte County and the Tantramar/Chignecto region—were analyzed to better understand the effectiveness of collaboration efforts (*see* Feist et al., 2020). Each of these initiatives involved engagement with stakeholders across different sectors, who came together with the common goal of adapting to climate change in their region. Fifty-one percent of the project participants surveyed felt that the collaboration was either very or extremely effective, with another 42% considering it to have been moderately effective. Participants also identified the qualities of collaboration (e.g., shared decision making, acquiring new knowledge, etc.) that they thought were most important to the process, and selected outcomes resulting from the collaboration (e.g., gaining a shared understanding, creative solutions, etc.) that resonated most strongly with them. The relationships between collaborative qualities (CQ) and the outcomes of collaborating are illustrated in network diagrams (*see* Figure 1.18), indicating which qualities were most influential to certain outcomes. The case studies show how collaborative initiatives can be used to effectively identify region-specific vulnerabilities and inform climate change adaptation action plans. They also show how individuals with various backgrounds can work together to collectively address complex problems and develop more robust adaptation measures tailored to regional contexts.

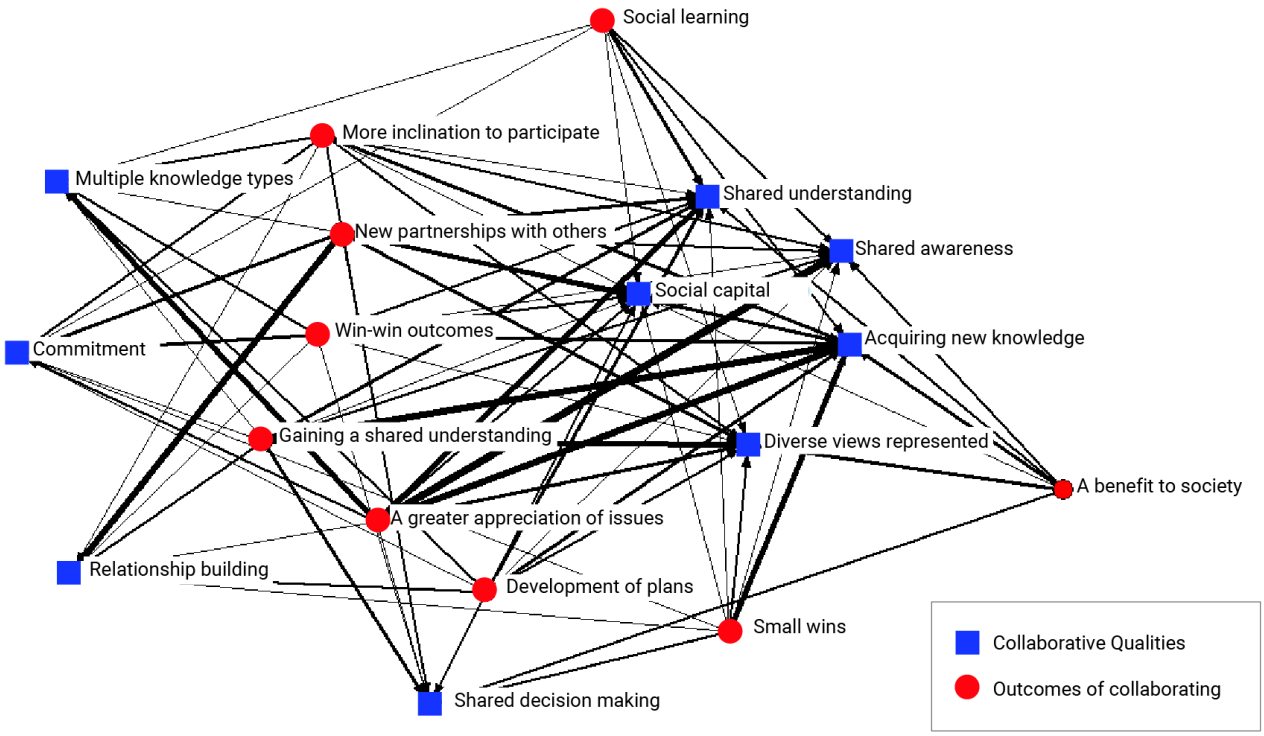

Figure 1.18: Network diagrams were used to display the relationships between qualities of collaboration in the process and achieved outcomes in the Tantramar/Chignecto Climate Change Adaptation Collaborative case study. The bold lines highlight linkages that were selected most often by participants, indicating the qualities (blue) that were considered to be the most influential for informing certain outcomes from the collaboration (red). The qualities and outcomes closer to the centre of the diagram are those that were deemed by participants as being most important. Sources: Feist et al., 2020; Feist, 2018.

1.6.2 Adaptation approaches

1.6.2.1 Collaboration and capacity building

Numerous initiatives in Atlantic Canada have included a dimension of capacity building and collaboration within provincial, municipal and regional governments, as well as across different sectors (*see* Table 1.5 and Case Story 1.12). While some provinces have climate change action plans that include adaptation actions, there is a need to further build capacity within governments to address climate change impacts and adaptation, and to work effectively with stakeholders.

Widespread collaboration on complex adaptation challenges has also led to the development of solutions that benefit multiple provinces. Provincial governments have supported municipalities in the development of tools, funding for peer-learning projects, and partnerships with NGOs and universities to deliver outreach programs. In New Brunswick, for example, provincial funding is available to community groups, municipalities, First Nations, non-profit organizations and institutions to develop adaptation plans, and to advance sustainable and environmental projects (Government of New Brunswick, n.d.d). Regionally, efforts towards climate change adaptation planning and action have involved pooling resources to effectively and efficiently serve a wider region, thereby avoiding competition between small communities for funds and grants. In all cases, collaboration has been enhanced by encouraging stakeholders to work on common interests and goals.

Table 1.5: Examples of collaborative adaptation initiatives in Atlantic Canada

PROJECT NAME AND LOCATION	DESCRIPTION
Natural and Nature-based Climate Change Adaptation Community of Practice	The *Natural and Nature-based Climate Change Adaptation Community of Practice* is coordinated by the New Brunswick Environmental Network and Nature NB (New Brunswick Environmental Network and Nature NB (2020) and supported by Natural Resources Canada. The Community of Practice (COP) is a multi-sector network that creates planning and education tools, shares information and collaborates to enhance natural and nature-based infrastructure project opportunities among various sectors. COP members work across the Maritimes and other parts of Canada on projects related to nature-based climate solutions and, through events and virtual tools (e.g., website directory, webinars, etc.), have the opportunity to share resources and educate each other about these important topics.

PROJECT NAME AND LOCATION	DESCRIPTION
Chignecto Climate Change Collaborative in New Brunswick and Nova Scotia	The *Chignecto Climate Change Collaborative (CCCC)* was created in January 2013 as a result of research on climate change impacts in the Chignecto region (the narrow strip of land connecting New Brunswick and Nova Scotia) (EOS Eco-Energy, 2021). More than 80 stakeholder groups came together in a workshop hosted by EOS Eco-Energy, a local, environmental non-profit organization, to create a regional climate change adaptation plan (EOS Eco-Energy, 2017, 2013). Today, the collaborative continues to implement the regional plan and offers professional development workshops for its members, networking events and public education. The group also erected a series of educational sea-level rise markers across the Chignecto Isthmus.
Building Asset Management in Newfound and Labrador program	The *Building Asset Management in Newfoundland and Labrador* initiative—led by Municipalities Newfoundland and Labrador and supported by the Federation of Canadian Municipalities (FCMs) Municipal Asset Management Program (MAMP)—is addressing the needs of smaller communities in Newfoundland and Labrador, where limited resources make climate change-related initiatives challenging (Municipalities Newfoundland and Labrador, 2021). This initiative is cohort-based and focuses on peer learning to make asset management training more accessible, and to build awareness and political will.
Climate change and resilient infrastructure in Newfoundland and Labrador	The *Building and Sustaining Infrastructure-Resilience through Targeted Climate Adaptation Training for Professionals in Newfoundland and Labrador* project is building capacity among engineers, planners and municipalities in the province to help inform planning and decision-making activities that will make infrastructure more resilient to climate change (Memorial University of Newfoundland, 2021). The project involves collaboration between Memorial University, the Government of Newfoundland and Labrador, Professional Engineers of Newfoundland and Labrador (PEGNL), Engineers Canada, Municipalities Newfoundland and Labrador and the Newfoundland and Labrador Association of Professional Planners and was supported by Natural Resources Canada.

PROJECT NAME AND LOCATION	DESCRIPTION
Building capacity and resilience to climate impacts in key economic sectors in Newfoundland and Labrador.	The *Building Capacity and Resilience to Climate Impacts in Key Economic Sectors in Newfoundland and Labrador* project is enhancing understanding of climate change impacts across sectors, identifying specific risks and opportunities to ensure that Newfoundland and Labrador is resilient to a changing climate, and building capacity among stakeholders to address risks and opportunities (Natural Resources Canada, 2021). The project involves collaboration between the following: the Government of Newfoundland and Labrador; the Newfoundland and Labrador Federation of Agriculture (NLFA); Fish, Food and Allied Workers; Newfoundland and Labrador Forest Industry Association (NLFIA); Mining Industry NL; and Hospitality Newfoundland and Labrador and was supported by Natural Resources Canada.
New Brunswick Climate Change Action Plan	New Brunswick's Climate Change Action Plan, *Transitioning to a Low-Carbon Economy* (Government of New Brunswick, 2016), contains an adaptation strategy supported by actions that aim to build capacity and resilience in communities, business sectors, infrastructure and natural resources by utilizing the province's long-established NGO network, through the New Brunswick Environmental Network (NBEN).
Educating coastal communities about sea-level rise in Prince Edward Island	The Government of Prince Edward Island is connecting communities to address local climate change impacts by building relationships and supporting the sharing of knowledge about storm-related impacts from past events. As part of the *Educating Coastal Communities About Sea-level Rise (ECoAS)* Project (Ecology Action Centre, 2018), researchers and graduate students from the University of Prince Edward Island Climate Research Lab facilitated workshops and held presentations in eight communities across the province to increase understanding and awareness about the impacts of sea-level rise, coastal erosion and storm surges.
Regional approach to climate change adaptation in New Brunswick	The northwest region of New Brunswick includes 24 administrative zones of varying size and capacity. In 2017, the Regional Service Commission received provincial funds to develop a single regional adaptation plan (Commission de services régionaux Chaleurs, 2021). The region aims to develop an integrated approach to climate change adaptation by pooling knowledge, assessing common threats at the regional and local scales, and proposing collaborative actions to address identified risks.

PROJECT NAME AND LOCATION	DESCRIPTION
New Brunswick Climate Change Adaptation Collaborative	The New Brunswick Climate Change Adaptation Collaborative (NBCCAC) was formed in 2013 in response to an increasing need for capacity building on climate change adaptation within a number of sectors that are facing risks associated with rising sea levels and increased storm events attributed to climate change (New Brunswick Environmental Network, 2018b). As a result, high-risk municipalities in the province are undertaking vulnerability assessments to inform municipal adaptation plans.
Nova Scotia's Climate Adaptation Leadership Program	Nova Scotia Environment's Climate Change Division is implementing a *Climate Adaptation Leadership Program* (Government of Nova Scotia, 2014) to build adaptive capacity within provincial government departments and between these departments and sectoral stakeholders. This approach is based on a learn-by-doing framework in which teams work together to develop and implement climate change adaptation strategies. The structured process includes online and in-person workshops and learning for all team members.
TransCoastal Adaptations: Centre for Nature-Based Solutions	The TransCoastal Adaptations: Centre for Nature Based Solutions at Saint Mary's University (TransCoastal Adaptations, n.d.) was founded in 2019 to respond to a need for applied experience in implementing coastal restoration projects. Its mission is to support the building of climate-resilient coastal communities and ecosystems by protecting, enhancing and restoring natural processes through innovative research, collaboration and the implementation of nature-based adaptation solutions. It involves integrated partnerships between academia, NGOs, Indigenous groups, and the private and public sector in Nova Scotia and Prince Edward Island.
Projet Adaptation PA	*Projet Adaptation PA* is a regional project aimed at identifying and implementing measures to reduce current and future impacts of coastal erosion and flooding in communities at risk within New Brunswick's Acadian Peninsula. The program involves people, communities and organizations working and learning together. The process proposed to each of the communities is as follows: 1) Scenarios and risks; 2) Maps and zoning; 3) Priorities and potential strategies; 4) Evaluation and selection of strategies; and 5) Implementation plans. (Projet Adaptation PA, n.d.)

Public outreach and education sessions addressing climate change adaptation occur regularly throughout the Atlantic region and engage a wide variety of public interest groups, including school-age children, community groups, sector-specific professional organizations and special interest groups (e.g., New Brunswick Environmental Network and Nature NB, 2020). Such initiatives are often led by community champions, involve strategic partnerships with research institutions, and receive financial support from local or provincial governments and other funding agencies (*see* Case Story 1.12). For example, the New Brunswick

Environmental Trust Fund (ETF) provides financial support to community groups, municipalities, First Nations, non-profit organizations and institutions to lead projects focusing on climate change education, and communication and outreach activities and programs (Government of New Brunswick, n.d.d).

Support networks for community adaptation have also been established through long-term partnerships with academia (Chouinard & Fauré 2018). These partnerships enhance the visibility of locally developed knowledge and research that focus on local issues (Chouinard and Fauré, 2018). These support networks have been led by academics or individuals who work in the public sector and have climate change expertise (Chouinard and Fauré, 2018).

Case Story 1.12: The Pays de Cocagne Sustainable Development Group (PCSDG): A catalyst for climate change adaptation

Coastal communities in southeast New Brunswick, particularly in the Cocagne watershed region, are directly affected by the impacts of climate change. This watershed occupies 400 km² and drains the waters of the Cocagne River and its tributaries into the Northumberland Strait. Coastal communities located in this region are affected by increasingly frequent storm surges (as occurred in 2000 and 2010), freezing rain (as in 2014 and 2017) and drought events (as in 2017; Roy and Huard, 2016). Aside from the increased frequency of storms, residents of Cocagne and Grande-Digue are also at risk of adverse health effects from saltwater contamination of their private water wells (e.g., Radio-Canada, 2019b).

With the help of the Pays de Cocagne Sustainable Development Group (GDDPC) and researchers from the Université de Moncton (Madore, 2020; Chouinard, 2016; Weissenberger and Chouinard, 2015; Chouinard and Weissenberger, 2014; Chouinard et al., 2013, 2012, 2011), residents in the Cocagne watershed region have been tackling climate change, and gaining expertise and deeper understanding about this issue in the process. The GDDPC's main mandate is to protect the Cocagne River and Bay watershed ecozone through a network of key players and numerous partnerships (Chouinard and Fauré, 2018). This mandate also includes participating in local governance and provincial public policy development, including climate change mitigation and adaptation planning.

1.6.2.2 Communication tools and resources

Public outreach opportunities have traditionally helped to educate the public about the science of climate change. More recently, public engagement has shifted towards discussions on community adaptation options, assisted by visual and plain language tools to aid communication. Such tools include flood-risk mapping, computer simulations, plain language brochures, infographics and public workshops (*see* Table 1.6). A low-tech example is the use of watershed maps showing land-use details, as used through the work

of the Maritime Natural Infrastructure Collaborative (MNIC, 2017). These maps can serve as visualization tools when meeting with communities, and they inform discussions about local ecosystem services and threats that may be impacting their delivery (e.g., pollution sources, wetland infill). Without visualization tools, communicating with various stakeholders about ecosystem services, watersheds and nature-based adaptation may be difficult, given the scope and complexity of the topics. Ultimately, these tools have proven to be effective at enhancing communication on climate change risks, engaging stakeholders in discussions about the role that natural areas can play in reducing vulnerability, and enhancing resiliency to climate change (Cheeseman, 2020), as well as being important ways in which individuals gain new knowledge (*see* Case Story 1.12; Feist et al., 2020). Finally, visualization tools have also proved helpful in communicating complex climate data in a variety of formats to a number of stakeholders, including governments, the private sector and the general public. Some of these tools are referenced below in Table 1.6.

Table 1.6: Examples of communications and data tools and resources in Atlantic Canada

TOOLS/DATA	DESCRIPTION
New Brunswick	
Historical coastal erosion data in New Brunswick	Coastal erosion data produced by the Government of New Brunswick, academic institutions and consultants is available for general use. This data includes local, regional and provincial trends in coastline and shoreline displacement (Government of New Brunswick, n.d.a).
Sea-level rise and flooding estimates in New Brunswick	Sea-level rise and flooding scenarios—based on projections of sea-level rise from the IPCC's Fifth Assessment Report—are available for coastal areas of New Brunswick (Daigle, 2017). These scenarios also consider the regional impacts of vertical land movement, redistribution of land glacier and ice sheet meltwater, dynamic oceanographic effects, land water storage and expected increases in the Bay of Fundy tidal range.
Flood information for New Brunswick	Flood mapping information—including flood lines, extents, flood risk areas and areas that were flooded during particular events—is available for general information purposes (Government of New Brunswick, 2019).
Regional wave run-up study for coastal sections of New Brunswick	Estimates of the potential impacts of wave run-up that can occur during storm surge events along coastal sections of New Brunswick (National Research Council, 2018).

TOOLS/DATA	DESCRIPTION
Prince Edward Island	
Coastal Impacts Visualization Environment	The Coastal Impacts Visualization Environment (CLIVE; University of Prince Edward Island Climate Research Lab, 2020) is a climate change impacts visualization tool that combines historical erosion data, IPCC model projections of future sea-level rise, aerial imagery and high-resolution digital elevation data to develop analytical visualizations of coastal erosion and future sea-level-rise scenarios.
Prince Edward Island Coastal Property Guide	The Prince Edward Island Coastal Property Guide (DV8 Consulting, 2016) provides information about risks to coastal properties, approaches for reducing risk, development rules and climate change impacts on the coast, including erosion and flooding from sea-level rise.
Prince Edward Island Coastal Hazard Assessments and Maps	Information on coastal hazards—erosion, sea-level rise, storm surge and waves—is available for Prince Edward Island. This data indicates the rate of change (i.e., erosion) in the coastline and the extent and likelihood of temporary (e.g., storm-related) and permanent flooding by 2100. The province-wide reliable and quantitative flood hazard information will be made available through an online map platform. For information on the hazards relating to specific property, a Coastal Hazard Assessment can also be requested from the Government of Prince Edward Island's Coastal Hazard Assessment Online Services. (Government of Prince Edward Island, 2021)
Prince Edward Island Coastal Infrastructure Vulnerability Assessment	Coastal hazards are being assessed for the likelihood of occurrence and the potential impacts that they will have on people, communities, structures and the natural environment. This assessment will identify infrastructure and facilities of high vulnerability on Prince Edward Island, to support decision-making relating to emergency management plans and the prioritization of adaptation measures (Parnham, 2021).
Nova Scotia	
Agricultural risk assessment tools for the grape and wine industry in Nova Scotia	Developed for the wine and grape industry in Nova Scotia, these tools allow users to explore the probability of certain risk events along the commodity value chain under different climate risk scenarios (Nova Scotia Federation of Agriculture, 2020).

TOOLS/DATA	DESCRIPTION
Newfoundland and Labrador	
Coastal Change in Newfoundland and Labrador	Online coastal story maps that illustrate connections between the province's glacial history, coastal landforms and processes, infrastructure, planning, climate change and sea-level rise, and provide resources to planners and decision-makers (Government of Newfoundland and Labrador, n.d.c).
All provinces	
Coastal Community Adaptation Toolkit	An interactive and query-based website (ACASA, n.d.), with supporting documents, designed to guide users in identifying locally appropriate adaptation options for managing coastal flooding and erosion. Target audiences are local governments and organizations that support local-level decision making.
Educating Coastal Communities about Sea-Level Rise project website	The website of the Educating Coastal Communities About Sea-Level Rise (ECoAS) Project (Ecology Action Centre, 2018), led by the Ecology Action Centre in Halifax, Nova Scotia, offers numerous resources for communities.

1.7 Moving forward

1.7.1 Knowledge gaps and research needs

Ongoing engagement with practitioners, researchers, NGOs, government employees and consultants has identified knowledge gaps and research needs, specifically in relation to social sciences perspectives on adaptation and social change, including:

- Better understanding and addressing viewpoints of Indigenous communities (Fenech and Arnold, 2018; Bartlett, 2017; Canadian Institutes of Health Research, 2015);
- Developing monitoring and evaluation tools (Guyadeen et al., 2019; Federation of Canadian Municipalities, 2017; Dupuis et al., 2013; BetterEvaluation, n.d.);
- Strengthening research on effective communication methods (Rahman et al., 2019; Lieske et al., 2014b; Nova Scotia Environment and Ecology Action Centre, 2014; University of Prince Edward Island Climate Research Lab, n.d.);

- Policy planning and adaptation budgeting (Baird et al., 2016); and
- Increasing understanding of how to approach relocation (Barrett, 2020; Power, 2019; Ross, 2017).

While these gaps and needs are not unique to Atlantic Canada, they are considered the most pressing for the region.

1.7.1.1 Applying two-eyed seeing in adaptation

As adaptation planning takes on increasingly complex challenges, the need for holistic and interdisciplinary approaches is becoming clear. *Etuaptmumk*, or Two-Eyed Seeing, is one approach for fulfilling this need (*see* Box 1.2) and has been successfully applied in areas other than adaptation. For example, the Institute of Indigenous Peoples' Health (IIPH) of the Canadian Institute of Health Research (CIHR) balances the different knowledge systems and ways of knowing in all phases of research (i.e., design, analysis, implementation and evaluation of interventions), and provides funding opportunities, including in other collaborative CIHR initiatives (Canadian Institutes of Health Research, 2015). This approach recognizes the limitations of the narrow focus on disease and illness that is common to many Western approaches. Instead, the IIPH approaches health and wellness in a holistic and interconnected manner by addressing the physical, emotional, mental and spiritual health of an individual (Canadian Institutes of Health Research, 2015). By utilizing multiple lenses and understanding existing connections, it will be possible to develop proactive adaptation planning to expand beyond the known, direct and physical impacts within one particular field.

Following are examples of initiatives being carried out: using oral histories to identify climate trends and linking them to climate indices; developing a culturally appropriate method for mapping Mi'kmaq cultural landscape values in Prince Edward Island and using Geographic Information System (GIS) software to assess their vulnerability within the coastal zone; and creating community-based climate monitoring networks using species identification resources in both Mi'kmaq and English (Fenech and Arnold, 2018). However, there remains a need for non-Indigenous organizations to understand the benefits of Two-Eyed Seeing and to implement this approach respectfully, appropriately and effectively in collaboration and conjunction with Indigenous partners. Resources, collaboration with Indigenous groups and documentation of best practices are gaps that can be addressed by building relationships, trust and recognition of leadership.

1.7.1.2 Monitoring and evaluation of adaptation initiatives

As adaptation initiatives grow in scope and complexity, the ability to monitor and evaluate efforts, and assess and improve the efficiency and effectiveness of these initiatives must also grow. While process-based indicators such as "number of total participants" are commonly used, such indicators cannot assess the outcomes of a project (e.g., increased adaptive capacity, enhanced resilience within a system). Approaches such as outcome mapping (i.e., planning, monitoring and evaluating development initiatives in order to bring about sustainable social change) and developmental evaluation (i.e., evaluation that supports ongoing learning and adaptation through iterative, embedded evaluations) are well suited to measuring progress in large multi-stakeholder systems that span multiple scales (BetterEvaluation, n.d.). The benefits of utilizing

rigorous monitoring and evaluation techniques in the design, delivery and assessment of climate change adaptation initiatives are currently under study at the UPEI Climate Lab in the areas of agriculture and adaption capacity building in Prince Edward Island (Arnold, 2020).

1.7.1.3 Effective communication

Communication is most likely to be effective when it is customized to the needs and interests of the target audience. The use of visualization techniques to communicate climate change impacts has improved the public's understanding of anticipated vulnerabilities (*see* Case Story 1.12; Lieske et al., 2014b; Nova Scotia Environment and Ecology Action Centre, 2014). The ability of visualization tools to collate and distill multiple datasets and communicate abstract concepts in an intuitive manner facilitates interpretation and understanding (University of Prince Edward Island Climate Research Lab, n.d.).

Other types of communication include participatory events that invite audience members to mark a line on the ground using props to indicate anticipated changes to coastlines, and photo simulations that depict expected water levels. Such a study was used to examine the effectiveness of communication between institutional actors within and outside government to build support for a dyke re-alignment and salt marsh restoration project in Truro-Onslow (Rahman et al., 2019). Visual graphs such as interpolated maps of projected climate variables can also help non-technical users to better understand the anticipated changes in our climate. New Brunswick has climate datasets and maps showing projected changes for 29 climate indices (*see* Northwest Regional Service Commission, 2019). New Brunswick's climate data sets and maps showcase conditions during the baseline period of 1980–2010, and provide climate projections for 2020, 2050 and 2080. Impacts to the public, apart from those of land loss and infrastructure at risk, are often less visible, and their connections to climate change may be more difficult to understand. Moving forward, effective communication of expected climate change impacts to areas such as biodiversity, agricultural production, public health—and how these impacts affect society—are needed.

1.7.1.4 Policy planning and adaptation budgeting

There are existing knowledge gaps in understanding how climate change affects all areas of governance and society, how policies can be developed to reflect climate change impacts, the costs of adaptation initiatives, and how to effectively build adaptive capacity throughout provincial and municipal governments. Addressing these gaps would help provincial and municipal governments to be proactive in setting policies that consider climate change adaptation. Adaptation funding has often manifested as a higher "cost of doing business" through reactive measures, however studies show that the benefits of planned actions to adapt to climate change in Canada generally exceed the costs (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter of the National Issues Report). Proactive adaptation initiatives are often prompted and co-funded through federal programs that are designed to serve multiple jurisdictions and to meet specific mandates. At the local and regional levels, there are many complex and unique needs that can fall outside of the parameters of such funding opportunities (Baird et al., 2016).

1.7.1.5 Managed relocation

Adaptation has to date been mostly reactive in nature. While awareness of flood and erosion risks influences the investment decisions of some existing and potential property owners, proactive adaptation at a community level, such as relocation, is rare and is only now beginning to be considered more broadly. Atlantic Canada does have some experience with managed relocation. Whereas the 1976 Kouchibouguac expropriation created animosity between residents and government authorities at the time and continues to reverberate negatively (Ross, 2017), the recent relocation of entire communities in Newfoundland seems to have resulted in positive outcomes, although such relocation is primarily promoted because of the provincial costs of service provision (Barrett, 2020). This includes the relocation of Little Bay Islands, in Newfoundland and Labrador, whose residents voted unanimously in favour of relocation, and who will maintain ownership of their houses so they can return for visits (Morin, 2019).

1.7.2 Emerging issues

Consultations, including interviews with practitioners, workshops, and meetings undertaken as part of this chapter have identified several issues of increasing concern for Atlantic Canada. These can be grouped into six categories: an inability to keep pace with the rate of change; limited effectiveness of adaptation initiatives due to external constraints; difficulties in coping with climate change impacts to natural systems; added complexity due to shared responsibilities across jurisdictions; lack of adaptation planning for new development; and advancing the region's response to Lyme disease.

1.7.2.1 Inability to keep pace with the rate of change

The diversity, intensity, frequency and complexity of climate change impacts are increasing, and adaptation efforts have been unable to keep pace. It is increasingly important that adaptation initiatives be designed and executed in a proactive manner, rather than being reactive. This includes the incorporation of different viewpoints (e.g., Two-Eyed Seeing) and disciplines to increase the reach, rigour and effectiveness of adaptation efforts, as well as equipping policy-makers and decision-makers with the skills and knowledge required to make appropriate decisions informed by public participation, especially those directly affected by climate impacts.

1.7.2.2 Coping with impacts on nature

It has proven difficult to generate public support, plan, design, budget and execute adaptation initiatives to help natural systems adapt to climate change impacts. In addition, the pressure that climate change impacts place on human health and food security is less well understood among the public and policy-makers, compared with impacts on physical infrastructure. The interconnectivities within natural systems and the importance of these ecological relationships are not always self-evident. For example, the increase in metabolism of some insects due to rising temperatures may lead to a population peak earlier in the season, potentially causing a phenological mismatch with the arrival of migratory birds, thereby affecting hatchling growth and development (Nantel et al., 2014). Furthermore, many of the existing initiatives that are mandated to protect and maintain the health of natural systems lack the scope, expertise and resources to address climate change impacts.

1.7.2.3 Added complexity of shared responsibilities across jurisdictions

Adaptation decisions can be challenging, especially where critical infrastructure is relied upon by multiple jurisdictions and failure of this infrastructure could result in cascading economic impacts beyond those of the direct impacts on the at-risk site. For example, the transportation and utilities corridor across the Chignecto Isthmus connects the Halifax Harbour to the rest of Canada and is critical for business continuity across Atlantic Canada. Approximately $24 billion in goods are exported from and $19 billion in goods are imported to Atlantic Canada, with most of these goods being transported through the Isthmus (Parnham et al., 2015). Not only is the infrastructure within this low-lying area of critical importance to trade, disruptions in access can severely impact food security in Newfoundland and Labrador, Prince Edward Island and Nova Scotia, which all rely on this corridor for much of their supplies. While the Chignecto Isthmus spreads over Nova Scotia and New Brunswick geographically, its importance extends to the entire country. This makes adaptation planning more complex. Who should contribute financially to increase the resilience of the Chignecto Isthmus in the face of rising sea levels? Who should decide how fortified this region should be to handle sudden, extreme weather events (e.g., storm surge)? How can provinces that rely on this trade corridor for food security develop alternative plans?

1.7.2.4 Lack of adaptation planning for new development

Over the last decade, a growing number of risk assessments have been carried out for vulnerable coastal locations across Atlantic Canada, and predictive tools have begun to precisely identify low-lying areas at risk of flooding and erosion. These tools are integral in properly implementing land-use planning approaches that will curtail the placement of new infrastructure in known areas of risk. However, many jurisdictions have not yet implemented planning policies or regulations, and continue to issue permits for new development in vulnerable locations. Becoming more climate aware and building capacity to combat the impacts of climate change offer communities and municipalities a unique opportunity to become more sustainable by considering climate change in their decision making and promoting themselves as resilient communities that plan for future conditions and ensure that they are less exposed to risks and remain sustainable. Some

municipalities/communities are beginning to see the market value of marketing themselves as communities that are resilient to the impacts of climate change.

1.7.2.5 Lyme disease: An opportunity to leverage across regions

Challenges around Lyme disease are exacerbated by the historical context that has minimized the severity of the disease, poor diagnostics, and hostile and polarized political dialogue inherited from the United States (Stricker and Johnson, 2014). The resulting public health response has consequently suffered from being considered as a low priority and having limited monitoring and oversight and inadequate public education initiatives (Lloyd and Hawkins, 2018). Medical treatment varies by province and physician. In Atlantic Canada, studies on the increasing geographic spread of the tick vector have been published for New Brunswick (Lieske and Lloyd, 2018) and Nova Scotia (McPherson et al., 2017), as has also been done for other areas of the country (Ogden, 2017). Moving forward, genuine and meaningful community-level engagement has the potential to advance both prevention and research initiatives (e.g., Lewis et al., 2018; Lieske and Lloyd, 2018; Stricker and Johnson, 2014).

1.8 Conclusion

Atlantic Canada is vulnerable to climate change impacts due to the cumulative effects of factors that relate to the region's physical geography, historic settlement patterns, demography, economy and community designs. The low-lying coastal geography of the region, which is subsiding in most locations, makes communities, infrastructure and natural resources particularly vulnerable to coastal impacts due to sea-level rise and a projected increase in the frequency of flood-inducing storm surge events. Social inequities further increase vulnerabilities. Anticipated changes in seasonal temperature extremes and precipitation will also expose Atlantic Canadians to the impacts of more frequent extreme events, such as heat waves, ice storms and seasonal inland flooding.

An ageing and declining population in the rural regions has a reduced social capacity to prepare for and recover from the impacts of climate change. Primary economic resource sectors that rely heavily on marine and coastal infrastructure are also disproportionately vulnerable. However, despite the region's small size and relatively limited human and financial resources—in comparison to the rest of the country—, adaptation efforts in recent years have been widespread. Local researchers, academics, NGOs and community champions have been resourceful in developing collaborative relationships. By building upon past research and work focused on impact risk assessment, they are shifting their attention from the delivery of adaptation tools, plans and policies to action at the community level through capacity building, nature-based solutions, and public education and outreach.

Common constraints related to the ongoing adaptation efforts discussed in this chapter include a lack of land use and development regulations in small communities (especially in unincorporated areas subject to high development pressures); limited capacity (e.g., human and financial resources, technical ability, etc.) to develop and implement adaptation plans and strategies; and the slow uptake and envisioning of a future that is much more heavily impacted by climate change. Efforts to overcome these challenges include the following:

- the use of pilot projects to explore innovative nature-based solutions for shoreline protection;
- coordinating multi-stakeholder adaptation efforts in the natural resource industries to reduce risks and leverage opportunities; and
- community-based initiatives to promote social adaptation among vulnerable populations, and to recognize both the physical and mental health impacts of extreme weather events.

The collaboration of diverse groups that pool or share resources to effectively and efficiently serve a wider geographic area and broader population has been key to increasing social capacity to adapt to climate change. The public outreach and educational opportunities that have been most effective tend to deliver key messages with context-specific data and examples, making use of visual and plain language tools to aid in communication. Partnerships with local Indigenous communities have strengthened the incorporation of local and Indigenous knowledge into adaptation planning. Collaborations have led to a greater appreciation of climate risks and adaptation options by the public, which benefits not only the environment and social learning, but should also lead to improved decision making and governance.

Atlantic Canada will remain at the frontline of climate change impacts, and strengthened adaptation efforts will be needed. Expanding collaborative efforts and exploring long-term solutions will continue to require different levels of government to play critical roles. Climate change is a shared problem that requires shared responsibility from all groups. Successful adaptation requires complementary action by sectors, businesses, research institutions, NGOs and individuals, given the localized nature of climate change impacts and the need for adaptation.

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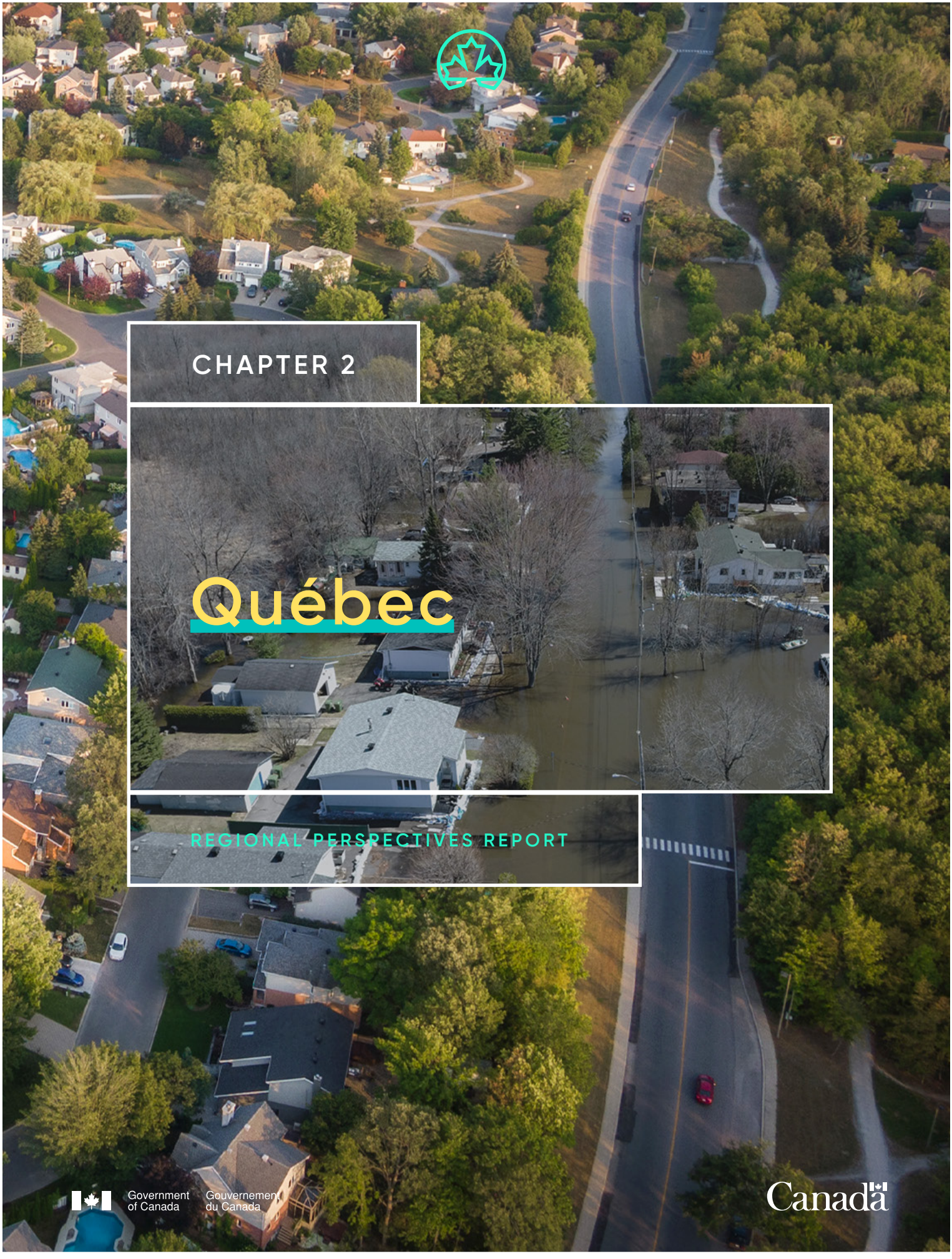

CHAPTER 2

Québec

REGIONAL PERSPECTIVES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key Messages

Vulnerability factors increase health risks associated with climate change (see section 2.2)

Physical and mental constraints, material and social deprivation, and lack of risk awareness are individual and social factors that can increase climate-change-induced health risks for individuals. In Quebec, to reduce the impact of these factors, interventions aimed at strengthening adaptive capacity and resilience of communities are being implemented for certain hazards such as heat waves and extreme weather events, which are expected to increase in frequency and severity.

Climate change poses significant risks to Indigenous Peoples and their environment (see section 2.3)

Throughout the province, and particularly in the North, climate change is threatening the land and the associated living heritage, along with Indigenous Peoples' connections with them. In this context, the sustainability of traditional subsistence practices, the transmission of Indigenous knowledge, the vitality of cultures and languages, and the spiritual well-being of the communities are at risk. By harnessing their resilience and adaptive capacity, Quebec's Indigenous communities are proactively planning and designing adaptation measures that consider their current needs and the needs of future generations.

Urban environments are facing increasing climate hazards (see section 2.4)

Urban areas are grappling with significant health, public safety and environmental degradation issues that will worsen in the coming decades due to climate change. In Quebec, cities are home to most of the population and are faced with growing problems such as heat islands and stormwater management. A growing number of municipalities are developing adaptation plans and strategies to better cope with climate hazards.

Coastal areas of eastern Quebec are under increasing threat (see section 2.5)

The coastal areas of eastern Quebec face significant coastal erosion and flooding issues. These problems are exacerbated by the reduction in ice cover that amplifies the impact of storms. In view of the severity of the cumulative impacts on coastal environments, coastal populations in Quebec are making changes to their land development practices to adapt to climate change.

Climate change impacts on water regimes, availability and quality (see section 2.6)

Quebec's lakes and rivers, including the St. Lawrence River, will be affected by climate change, which will modify water levels, flood risks, and water availability and quality. In response to potential changes in water regimes, Quebec is implementing adaptation measures, such as updating flood zone mapping, creating a flood forecasting system and protecting wetlands.

Ecosystem services play an important role in adaptation (see section 2.7)

Quebec's population relies on services provided by ecosystems to adapt to climate change. However, Quebec's ecosystems are themselves impacted by climate change. Several methodologies and tools for monitoring biodiversity have been developed to support decision-making in order to improve the conservation of ecosystems and maintain the ecological services they provide.

The agricultural and fisheries sectors will experience gains and losses (see section 2.8)

In Quebec, the agricultural, fisheries and aquaculture sectors could experience gains and losses in productivity, the emergence of new crop pests, and the northward migration of fish stocks due to climate change. Stakeholders in these sectors have initiated adaptation efforts by developing and using decision support tools that consider climate change in their practices.

The energy, forestry and mining sectors will be particularly impacted by climate change (see section 2.9)

Quebec's main natural resource sectors, namely energy, forestry and mining, will be particularly impacted by climate hazards. These hazards may impact operations, production, facilities and maintenance activities in these sectors. Producers are gradually adapting their decision-making processes and management methods to deal with climate change.

Tourism and financial sectors are feeling the impacts of climate change (see section 2.10)

Some industries, such as tourism and the insurance and financial service sectors are particularly sensitive to climate variations. In the last five years, a few companies, including some in the ski industry, have shown a proactive approach by implementing measures from a long-term planning perspective.

2.1 Introduction

2.1.1 Introduction

This chapter outlines current knowledge about the impacts of climate change on the population, the natural environment, the built environment and the economic sectors of Quebec, as well as the measures and initiatives that can be implemented to adapt to these impacts. It also incorporates new knowledge and research results that have become available since the publication of Ouranos' 2015 summary of knowledge on climate change knowledge in Quebec, entitled *Synthèse des connaissances sur les changements climatiques au Québec* (2015c).

2.1.2 Background

Quebec covers a vast territory of nearly 1.7 million km^2 that spans several distinct climatic zones and ecosystems, which harbour a rich biodiversity (*see* Figure 2.1) (Institut de la statistique du Québec, 2018a; Ministère des Forêts, de la Faune et des Parcs du Québec, 2003). The Far North is characterized by tundra, taiga and permafrost; the central region by boreal forest; and the south by mixed forest and the St. Lawrence Lowlands. The province also has an extensive river system and is bordered by the Atlantic Ocean to the east, the Arctic Ocean to the north, and James Bay and Hudson Bay to the west. The St. Lawrence River Basin is the largest drainage basin in Quebec and provides drinking water for 2.5 million people (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d). Because of this wide diversity of environments, the impacts of climate change vary greatly, affecting the entire territory's human population, socio-economic activities and living environments.

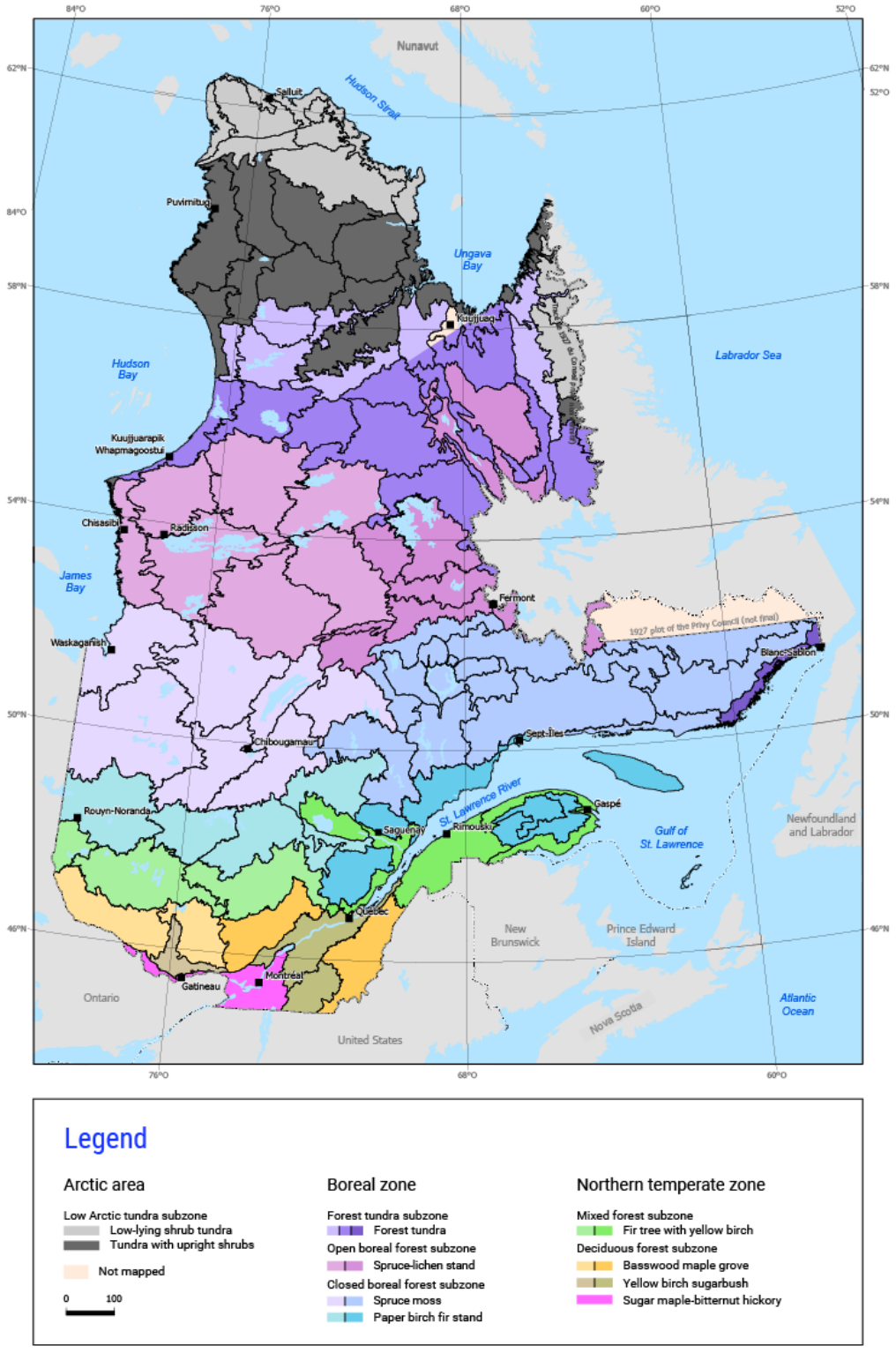


Figure 2.1: Vegetation zones, bioclimatic domains and ecological regions of Quebec. Source: Ministère des Forêts, de la Faune et des Parcs du Québec, 2021.

Quebec is the second most populous province in Canada with an estimated population of more than 8,500,000 in 2019 (Institut de la statistique du Québec, 2020). Most of the population (80%) is concentrated in urban centres in the south of the province and along the St. Lawrence River (Institut de la statistique du Québec, 2020). A significant proportion of Quebecers live in conditions of socio-economic insecurity or have vulnerabilities associated with their health status or location. As a result, they are particularly sensitive to the impacts of climate change (Crespo, 2019; Massé and Desbiens, 2017; Institut national de santé publique du Québec, 2006).

Furthermore, according to the 2016 Census, nearly 200,000 Quebecers belong to one of the 11 Indigenous nations of Quebec (Statistics Canada, 2016a), whose way of life involves subsistence activities and cultural practices associated with Indigenous knowledge. Climate variability exposes them to issues with food security as well as public safety, and can affect their culture and their rights, as these activities are strongly linked to the land, which is itself influenced by the climate.

Several key sectors of the Quebec economy are affected by climate change, directly or indirectly, including agriculture, fisheries, aquaculture, forestry, tourism, mining and renewable energy.

Urban areas are grappling with issues such as the heat island effect and stormwater management problems that will be exacerbated by climate change. As most cities are located near watercourses, they are also sensitive to hydrological variations, as evidenced by the impacts associated with the flooding events that took place in Quebec in 2019 and 2017. The coastal communities of eastern Quebec, for their part, are facing serious problems related to marine erosion and flooding.

2.1.3 Quebec's changing climate

There is no denying climate change, and human influence on greenhouse gas (GHG) emissions is well established (IPCC, 2014a). Since 1950, the average temperature in Quebec has risen by 1 to 3 °C depending on the region (Ouranos, 2015b). Significant increases in the number of hot nights and days and in the duration of heat waves were observed between 1951 and 2010 (Ouranos, 2015b). During this period, an increase in rainfall was also observed, particularly in southern Quebec (Ouranos, 2015b). Since global GHG emissions have not abated, these trends are likely to continue. Without significant GHG mitigation measures, annual average temperatures in Quebec could increase by 3.5 °C relative to the 1981–2010 period by 2050, according to the RCP8.5 emissions scenario (Ouranos, 2015b). By 2080, the corresponding increase in temperatures could be more than 6° C (*see* Figure 2.2 and the portal *Portraits climatiques d'Ouranos* [Ouranos, 2018c] for additional figures; Ouranos, 2018c).

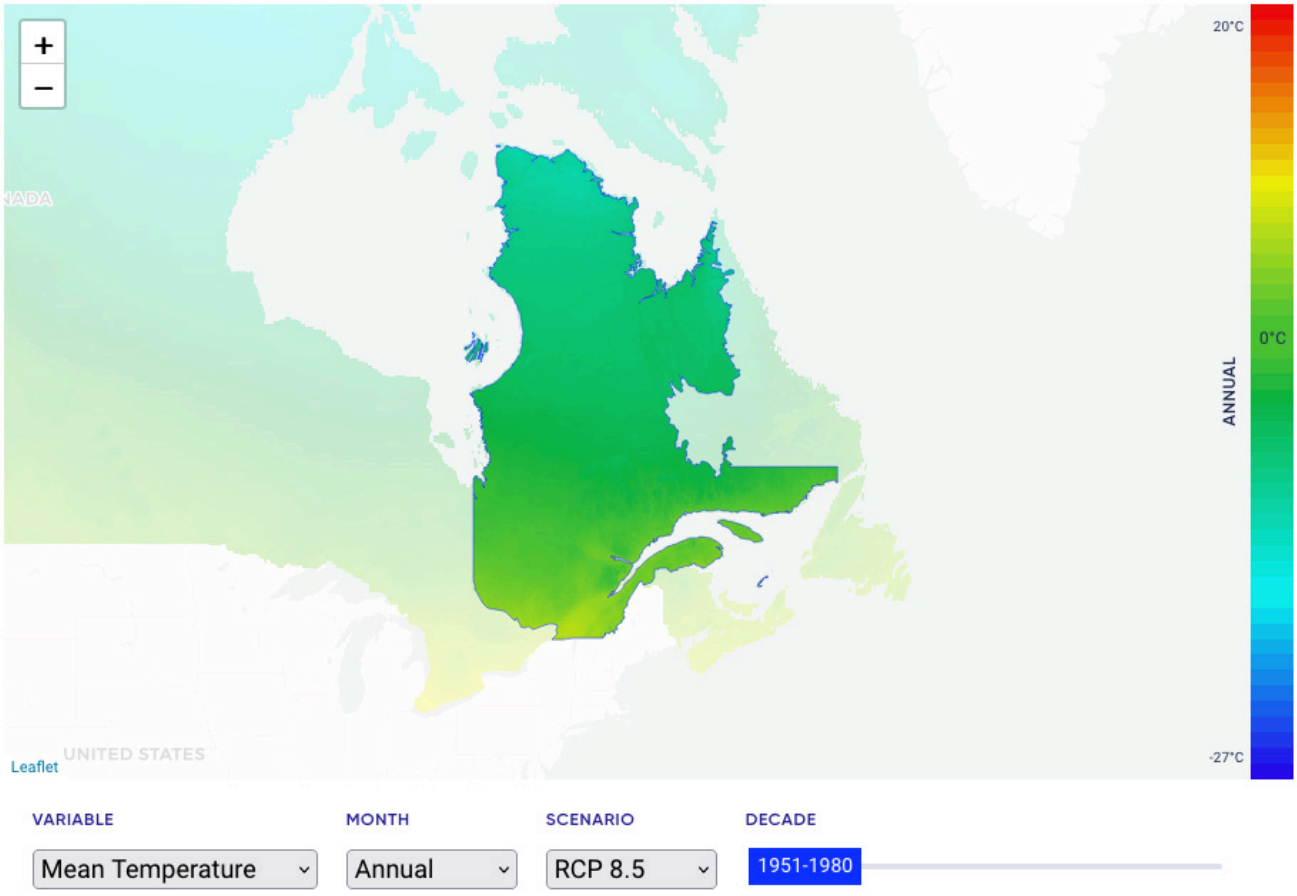


Figure 2.2: Interactive regional map of Quebec (adapted from the climatedata.ca portal) which provides information on various climate variables from 1980 to 2100 based on the high emission scenario (RCP8.5). Source: climatedata.ca

This widespread warming has caused and will continue to cause upheavals in the climate system, in particular by exacerbating climate extremes and altering seasonal norms and seasonal variability. For example, we can expect to see an increase in the duration, frequency and intensity of heat waves and hot nights (Ouranos, 2015b). By 2050, the growing season is expected to be up to 20 days longer across the province, while the frost season could decrease by between 20 and 34 days in the southern part of the province and the Gulf of St. Lawrence (Ouranos, 2015b).

The projections also indicate increases in winter and spring precipitation totals by 2050, as well as an increase in the amount of rainfall on rainy days (Ouranos, 2015b). This is compounded by an increase in the frequency, length and intensity of heavy rainfall events (during which precipitation exceeds 10 mm) across Quebec (Ouranos, 2015b). In addition, the maximum five day precipitation, a particularly important flood indicator (Ouranos, 2018c), is expected to increase. At the same time, by 2050 the amount of snow on the

ground is expected to decrease across most of the province . This trend is expected to be more pronounced in southern Quebec, where snowfall will peak in February rather than March, with less accumulation relative to 1971–2000 (Ouranos, 2015b).

Several models for the 2081–2100 period project an increase in the probability of prolonged precipitation-free periods (Ouranos, 2015b). Although there is still a lack of consensus on the results of the observed trends, the climate change signal becomes clearer by the end of the century. Decreased moisture values in the top 10 cm layer of soil are also projected for the same period (Ouranos, 2015b). This coincides with a trend of more severe low-water periods in the summer (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques – Expertise hydrique et barrages, 2018a), possibly associated with drought. However, low-water periods could be interspersed with more intense flooding events in summer and fall across a larger portion of southern Quebec. Other hydrological changes, such as increased average flows during winter and earlier spring freshets, could occur by 2050 due to climate change (Lachance-Cloutier et al., 2018; Tilmant et al., 2017; Ouranos, 2015b).

Decreased sea-ice coverage, a shorter sea-ice season (Galbraith et al., 2017; Senneville et al., 2014) and an increase in relative sea level in the eastern part of the province (Boyer-Villemaire et al., 2016; James et al., 2014) are also anticipated.

2.1.4 Overview of climate change impacts

These changes have had and will continue to have major impacts on human health, ecosystems and infrastructure in Quebec. Some of these impacts will translate into costs or opportunities for citizens, businesses and various levels of government, and are already beginning to be observed.

Since the late 1990s, the Quebec government has been working to identify the biophysical impacts of climate change and develop measures aimed at reducing climate vulnerabilities and associated risks (Ministère du Développement durable, de l'Environnement et des Parcs, 2012). Two government climate change action plans have been adopted and implemented to address these issues (Gouvernement du Québec, 2012). Quebec has also adopted a climate change adaptation strategy entitled *Stratégie gouvernementale d'adaptation aux changements climatiques, 2013–2020*, that includes 17 objectives related to public well-being, the continuation of economic activities, the longevity and safety of buildings and infrastructure, and the maintenance of essential ecological services (Ministère du Développement durable, de l'Environnement et des Parcs, 2012). The implementation of the 2013–2020 climate change action plan is supported by a dedicated fund that has been used for numerous research studies and climate change adaptation actions.

The following sections present the state of knowledge on the impacts of climate change on health, Indigenous populations, urban and coastal environments, water, ecosystem services, as well as on various economic sectors in Quebec. Adaptation measures are also discussed, along with the various initiatives that are already underway in Quebec.

Note that the proposed climate change adaptation measures do not imply that the need to reduce GHG emissions is over. Adaptation is a response to potential long-term future changes, as well as climate change that is locked into the system because of the GHGs that have already been emitted into the atmosphere. It

is essential to continue efforts to reduce emissions to avoid the most severe climate change scenarios, to which it could be impossible to adapt. At the same time, adaptation measures should not lead to an increase in GHGs emissions. Adaptation actions that increase the risk of adverse climate-related outcomes and vulnerabilities are considered maladaptation (Barnett and O'Neill, 2010).

2.2 Vulnerability factors increase health risks associated with climate change

Physical and mental constraints, material and social deprivation, as well as lack of risk awareness are individual and social factors that can increase climate-change-induced health risks for individuals. In Quebec, to reduce the impact of these factors, interventions aimed at strengthening adaptive capacity and resilience of communities are being implemented for certain hazards such as heat waves and extreme weather events, which are expected to increase in frequency and severity.

Individual and socio-economic factors make some individuals and groups particularly vulnerable to climate change. Climate change increases the vulnerability of some individuals and groups—people with mobility constraints or those who are predisposed to or suffering from mental and physical illnesses –, lack financial or social resources, or have a poor understanding or misguided perception of the risks. Moreover, the impacts of these factors may differ between genders and between certain trades or occupational groups. Measures that target vulnerability factors, such as urban greening in low-income neighbourhoods, implementing warning systems and investing in the rehabilitation of old housing and infrastructure, are good for public health and therefore reduce health inequalities.

2.2.1 Introduction

Vulnerability, which can be defined as the propensity or predisposition to be adversely affected, may be related to individuals and their environment (IPCC, 2014b). Individual and socio-economic factors make some people and groups particularly vulnerable to climate change. Since Quebec has an aging population (Institut national de santé publique du Québec, 2020a) and a significant proportion of the population is socio-economically disadvantaged (Crespo, 2019), the province has many vulnerability factors that can increase social inequalities and that are important to address.

The characteristics of the environment concerned and the type of hazards to which people are exposed will also affect their vulnerability. For example, urban environments (*see* Section 2.4), and rural or coastal environments (*see* Section 2.5) may impact populations, buildings and infrastructure in distinct ways. Northern and Indigenous populations (*see* Section 2.3) also have vulnerability factors.

2.2.2 Mobility and physical health

According to research conducted in Quebec on the links between health and climate change, mobility constraints and physical health problems are vulnerability factors since they can compound existing problems or create new ones (Bélanger et al., 2016; Bélanger et al., 2014). For example, although an increasing proportion of the population over the age of 65 is functionally healthy (Institut de la statistique du Québec, 2012), the likelihood of developing physical or mental conditions that may be exacerbated by the impacts of climate change increases with age (Roy et al., 2019; Kenny et al., 2010). As a result, older adults with chronic health conditions—particularly cardiovascular, pulmonary or renal disease—are at greater risk of experiencing a worsening of their pre-existing health problems and of dying during hot, cold and smoggy conditions (Leyva et al., 2017; Vanasse et al., 2017; Bunker et al., 2016; Laverdière et al., 2016; Simoni et al., 2015; Krstić, 2011). In fact, some studies have shown that a 1°C temperature rise increases cardiovascular (3.44% increase) and respiratory (3.6% increase) mortality (Bunker et al., 2016).

In addition, changing weather conditions (e.g., heat waves, severe cold, intense precipitation) make it difficult for people to use their scooters, canes or walkers to get around and perform daily tasks (Muscedere and Heckman, 2019). Snowstorms and wet weather increase the risk of falls (Modarres et al., 2014; Morency et al., 2012), which can result in hip fractures, among other injuries. These types of injuries, which are particularly prevalent among older adults, can be fatal: 20% of seniors who sustain a hip fracture die within a year (Public Health Agency of Canada, 2014). Studies on this topic tend to show that, in addition to the immediate consequences for physical health, exposure to various climate related hazards increases the risk of death and of developing chronic diseases, such as cardiovascular or respiratory diseases (Laverdière et al., 2016; Lamond et al., 2015; Bélanger et al., 2014; Lowe et al., 2013; Kosatsky et al., 2012; Bayentin et al., 2010).

Research conducted outside Quebec on the impacts and risks of natural disasters for people with disabilities or limited physical autonomy tend to show that they are more vulnerable than the general population, because of the greater difficulty of evacuating them and ensuring that they quickly receive emergency assistance (Van Solm et al., 2017; Alexander, 2015). Since the frequency and intensity of extreme weather events are expected to increase, it will be important for future research to examine physical constraints as a factor of vulnerability to natural disasters in Quebec, and to study ways to reduce the health inequalities that this factor accentuates in a changing climate.

2.2.3 Mental health

In Quebec, few in-depth studies have examined mental health as a factor of vulnerability to climate change, although research on this topic represents an important component of vulnerability and adaptation studies in public health and safety (Roy et al., 2019; Hayes et al., 2018; Hayes and Poland, 2018). Some authors have proposed mental health indicators to better understand the perceived adverse health impacts of heat in low-income neighbourhoods (Bélanger et al., 2016; Bélanger et al., 2014). Other researchers have explored the impacts of natural disasters on mental health in the short, medium and long term, including older adults' reports of intense stress, fear and worry about their physical security following the 1996 Saguenay floods and the 1998 ice storm (Maltais, 2016, 2007). One study conducted in the province involved a health and social assessment that documented the range of impacts on physical and psychological health reported by

residents following flooding in southern Quebec in 2019, and identified intervention strategies to support resilience in affected communities (Généreux et al., 2020). This study demonstrated that flooding had significant impacts on the mental health of directly affected residents. It supports international studies on the associations between extreme weather events and post traumatic stress disorder (Goldmann and Galea, 2014).

An aspect that is still rarely investigated in Quebec, perhaps with the exception of studies conducted in an Indigenous context (Fuentes et al., 2020; Landry et al., 2019; Basile, 2017), is the impacts of climate change on well-being and overall health. Several recent studies focused on the concept of eco-anxiety have documented and conceptualized the psychological distress experienced by individuals in the face of environmental degradation and the impacts of climate change. How these experiences hinder or enhance the resilience of various social groups in Quebec is a research topic that can inform climate change adaptation efforts in the future.

2.2.4 Material and social deprivation

Material deprivation refers to the inability to afford basic goods and services (e.g., food, shelter, a healthy environment) and to engage in activities, such as work. Social deprivation refers to the "fragility" of social ties within a family and with friends and other people who provide emotional and material support. It may also reflect difficulties associated with integration and participation in social relationships within the local community, such as recreational or educational activities (Pamplamon et al., 2014).

According to studies conducted in Quebec, social and material deprivation makes individuals particularly vulnerable to climate hazards in a range of situations, especially during periods of extreme heat. The cumulative physical and mental health consequences of living in housing that is not designed to manage heat (i.e., not air-conditioned, poorly ventilated, poorly insulated, or difficult to cool), or living in a disadvantaged neighbourhood, are inversely correlated with the capacity to adapt to coping with higher summer temperatures (Bélanger et al., 2016; Ngom et al., 2016; Bélanger et al., 2015; Laverdière et al., 2015; Cazale and Dumitru, 2008). Older adults, who typically cannot afford higher-quality housing, are more likely than the rest of the population to reside in housing that is poorly adapted to adverse weather conditions (Valois et al., 2018; Laverdière et al., 2016, 2015).

There are few Quebec studies that have directly examined the influence of social deprivation variables (such as being single or living alone; contact with children, extended family, or friends; and participation in social activities) on health during heat waves or other climate change hazards (Bustinza and Demers-Bouffard, 2019). However, evaluations of different versions of a heat action plan for Montréal showed that some measures (e.g., home visits and daily patient calls) appear to have reduced mortality among sick older individuals who may be socially isolated (Benmarhnia et al., 2016).

2.2.5 Gender

Until recently, gender-based analysis of the impacts of climate change has been generally lacking in empirical research on climate change impacts. The bulk of the work done in this area is rooted in the realities of

developing countries (Moosa and Tuana, 2014; Goh, 2012). In general, the aim of these studies has been to assess the vulnerabilities experienced by women due to unequal socio-economic conditions (income, social capital, power, access to basic goods and services) and caregiving roles and responsibilities. In fact, in many countries, since women are responsible for their children's well-being and food security, they are even more dependent on the success of their own production system without having equivalent decision making power (Food and Agriculture Organization of the United Nations and CARE, 2019; Food and Agriculture Organization of the United Nations, 2017). Owing to these unequal conditions, climate hazards (drought, floods, extreme weather events) take a greater toll on these women and their children. Note that children can be particularly vulnerable to climate change as they are entirely dependent on adults for their care and for protection from harm (Stanberry et al., 2018). Studies conducted on these issues aim to identify measures for building resilience to more severe climate hazards.

While gender inequality takes different forms in Quebec, much work remains to be done to identify the specific impacts of climate change on women, particularly those who are materially and socially disadvantaged (Duncan, 2008). In the Quebec literature, maternal and child health, as well as food insecurity (particularly in Indigenous communities), are the most frequently studied themes. For example, rising temperatures have been shown to promote the formation of certain air pollutants and allergenic pollen, putting children at increased risk for respiratory problems (e.g., asthma) (Nicolle-Mir, 2017; Schnell and Prather, 2017; Tetreault et al., 2016; Kelly and Fussell, 2015; D'Amato et al., 2013; DellaValle et al., 2012). Some studies have shown that extreme heat events also increase the likelihood of miscarriage (Auger et al., 2017a), sudden infant death syndrome (Auger et al., 2015), preterm birth (Auger et al., 2014) and congenital malformations, such as heart defects (Auger et al., 2017b) or neural tube defects (Auger et al., 2017c). Pregnant women are also at risk for placental abruption, a complication that can be life-threatening to both mother and baby (He et al., 2018).

Research conducted as part of Project Ice Storm following the 1998 ice storm suggests that children born to mothers who have been exposed to extreme weather events are more likely to develop physical and mental health issues (King et al., 2020). The conditions studied in connection with the 1998 ice storm include autism (Walder et al., 2014), eating disorders (St Hilaire et al., 2015), asthma (Turcotte-Tremblay et al., 2014), obesity (Liu et al., 2016; Cao-Lei et al., 2015) and an overactive immune system (Cao-Lei et al., 2016; Veru et al., 2015). Apart from this work (which examines the impacts of natural disasters on intrauterine health), there is a limited body of research in Quebec that focuses on the impacts of climate change on the health of children and adolescents.

2.2.6 Outdoor work and emergency professionals

The literature suggests that individuals working in certain trades or professions are more exposed to climate hazards. This is true for health and public safety professionals (police officers, firefighters) as well as outdoor workers (farmers, blue-collar workers, lineworkers, etc.). An exploratory study conducted in 2019 by the Institut national de santé publique du Québec (INSPQ) on the psychosocial realities of workers in relation to the increasing frequency of extreme weather events (heat waves, floods, storms and forest fires) helped to expand the state of knowledge on this issue. The psychosocial impacts of climate hazards, such as storms on workers, are much better documented than are the effects of floods, forest fires and heat waves (Adam-

Poupart et al., 2019). According to this study, workers reported that these events also had some positive impacts. The appreciation expressed by victims and the sense of pride workers gain from assisting with crisis management are factors that help counterbalance the disproportionate negative psychosocial impacts to which these workers are exposed.

Studies have also shown that rising temperatures and air pollutant concentrations may increase the risk of respiratory problems and cardiovascular disease in workers (Levi et al., 2018; Adam-Poupart et al., 2015a; Adam-Poupart et al., 2014, 2013; Gubernot et al., 2014). Heat also increases the likelihood of workplace accidents and can cause dizziness, cramping, nausea and physical fatigue (Levi et al., 2018; Adam-Poupart et al., 2015b, 2014). Outdoor workers, primarily in forestry and agriculture, also have a higher prevalence of zoonotic diseases (i.e., diseases transmitted from vertebrate animals to humans), such as Lyme disease and West Nile virus, which are expected to become more common with climate change (Bouchard et al., 2017; Briand et al., 2017; Aenishaenslin et al., 2014; Ferrouillet et al., 2012).

Individuals who spend more time out of doors are more often exposed to adverse weather conditions (heat, cold, ultraviolet radiation) and air pollutants (ozone, fine particulate matter, etc.), as well as increased cardiovascular strain (Auger et al., 2017d; Adam-Poupart et al., 2015b, 2013; Ali and Willett, 2015; Labrèche et al., 2013). They are also less likely to take preventive measures such as staying at home, limiting exertion, or seeing a health care professional (Valois et al., 2016a; Lowe et al., 2013). In addition, some studies have shown that individuals working in hot indoor environments, such as bakeries and foundries, may be negatively affected by rising temperatures if measures are not taken to cool the work environment or reduce exertion (Xiang et al., 2014).

2.2.7 Misperception of risk

Numerous studies, including those of the Observatoire québécois de l'adaptation aux changements climatiques (OQACC), have shown that adaptive capacity and the ability to cope with climate hazards do not depend solely on available financial and social resources (Observatoire québécois de l'adaptation aux changements climatiques, n.d.). In addition to these factors, perceptions and beliefs expressed by survey respondents have repeatedly shown a lack of awareness of the risks that various climate hazards may pose to their health (Valois et al., 2018, 2017e; Koerth et al., 2017; Aenishaenslin et al., 2015). For example, during provincial consultations following the 2017 spring floods, it was found that a significant number of people living in flood-prone areas were unaware of the risk to them. This finding prompted the government to undertake work to update the mapping of flood-prone areas in Quebec (CNW Telbec and Ministère des Affaires municipales et de l'Occupation du territoire, 2017).

It should be noted that people also lack awareness of the increasing risk posed by vector-borne diseases (including zoonotic diseases such as Lyme disease, rabies and West Nile virus) and waterborne diseases (e.g., *Campylobacter* or *Escherichia coli* infections). Given the positive link with warming temperatures and precipitation (Wu et al., 2016), vector-borne and waterborne diseases are likely to affect more and more people owing to a general lack of awareness of the risks involved. For example, a 2018 Quebec study involving approximately 2,000 Quebec residents revealed that about a third of participants were unaware that their municipality was located in a Lyme disease risk area, and most of them felt they were not at risk

of contracting the disease (Observatoire québécois de l'adaptation aux changements climatiques, 2019). This finding is quite worrisome as the peak incidence for Lyme disease is among children 5 to 9 years of age and adults 55 to 59 years of age (Onyett and the Canadian Paediatric Society, Infectious Diseases and Immunization Committee, 2014). Lastly, due to warmer temperatures, the growing season for, and the range of, ragweed—a plant that produces allergenic pollen—is increasing in Quebec (Larrivée et al., 2015). Although ragweed does not pose a serious threat, the expansion of its range nonetheless constitutes a public health issue because of the costs to Quebec society (Larrivée et al., 2015). An upcoming OQACC study on behaviours that can be adopted to reduce exposure to ragweed pollen will shed more light on possible misperceptions of this health risk (Observatoire québécois de l'adaptation aux changements climatiques, 2019).

2.2.8 Adaptive measures

Many adaptation measures have been implemented in Quebec to reduce the cumulative effects on social inequalities of factors of vulnerability to climate change. This section provides an overview of some of these measures.

Evaluations of surveillance systems and response plans for heat waves or extreme heat events have found that close and regular monitoring of individuals with physical and mental health conditions reduces heat-related morbidity and mortality (Benmarhnia et al., 2016). The Montréal area extreme heat response plan includes awareness campaigns on preventive behaviours that target the most vulnerable neighbourhoods, in addition to the provision of air-conditioned shelters and longer outdoor pool hours (Centres intégrés universitaires de santé et de services sociaux du Centre-Sud-de-l'Île-de-Montréal, 2018). It should be noted that 13 health regions in Quebec have adopted similar heat action plans (Valois et al., 2017d). However, no evaluations have been conducted on the effect of these plans on vulnerable groups.

Other preventive adaptations that have been identified in the literature include promoting access to air-conditioned community spaces for people with health problems and encouraging people to limit the time they spend outdoors during hot and smoggy weather (Kaiser et al., 2016; Valois et al., 2016b; Bélanger et al., 2015). An automated telephone alert system developed as part of a pilot project in the Montérégie region was found to have encouraged older adults to adopt preventive measures such as spending time in cool places (+18% compared with the control group) and drinking water (+7% compared with the control group) during heat events (Mehiriz et al., 2018; Mehiriz and Gosselin, 2017).

Health care institutions have an important role to play in facilitating adjustments to settings and practices to support caregivers, daycare centres and schools. Some of them have established personalized alerts or large-scale awareness campaigns and are using these channels to educate parents about the importance of adopting preventive behaviours. These measures are effective because parents tend to be receptive to information that can promote their children's well-being (Laferriere and Crighton, 2017; Neidell, 2009).

Recent research conducted from a climate justice perspective indicates that increasing tree canopy coverage in less affluent neighbourhoods is crucial as these areas are more likely to experience urban heat island impacts due to the high prevalence of impervious surfaces (Ziter et al., 2019). This finding has led to the initiation of a variety of urban heat island mitigation projects in Quebec. These initiatives have helped improve the quality of life in disadvantaged neighbourhoods by increasing the sense of security, social cohesion and

autonomy of resident communities, in addition to potentially increasing thermal comfort (Beaudoin, 2016; Beaudoin and Gosselin, 2016).

Another measure that has proven beneficial for groups experiencing varying levels of material and social deprivation is upgrading older housing (e.g., insulation, ventilation, air conditioning, greening), residential and long-term care facilities and hospitals. This benefits older adults with limited mobility or autonomy in particular (Gervais and Laliberté, 2016; Poulin et al., 2016; Fisk, 2015; Mavrogianni et al., 2012; Howden-Chapman et al., 2007).

Lastly, Quebec's Multi-Party Observatory on Zoonoses and Adaptation to Climate Change was created in 2015 to monitor the evolution of zoonotic diseases, infectious diseases that can be transmitted from an animal to a human, and to prioritize actions based on the risks these diseases pose to the general public and to groups with risk factors (Institut national de santé publique du Québec, 2018; Observatoire québécois de l'adaptation aux changements climatiques, n.d.).

2.3 Climate change poses significant risks to Indigenous Peoples and their environment

Throughout the province, and particularly in the North, climate change is threatening the land and the associated living heritage, along with Indigenous Peoples' connections with them. In this context, the sustainability of traditional subsistence practices, the transmission of Indigenous knowledge, the vitality of cultures and languages, and the spiritual well-being of the communities are at risk. By harnessing their resilience and adaptive capacity, Quebec's Indigenous communities are proactively planning and designing adaptation measures that consider their current needs and the needs of future generations.

The magnitude of the observed climate change and the speed at which changes are expected to materialize are occurring in a changing socio-economic context. Significant population growth and increased development are simultaneously putting pressure on the ancestral territories that Indigenous Peoples have occupied since time immemorial as well as on the communities (remote or peri-urban) in which they live. Together, these various impacts are profoundly altering their way of life and are likely to compromise their quality of life because of the risks they pose to individual health, infrastructure, homes, jobs and natural resource development activities. While Indigenous Peoples have demonstrated great resilience and agency in the face of change for generations, the magnitude and nature of the current climate transformations threaten to undermine their capacity to adapt. However, many communities already have climate change adaptation plans or are taking concrete steps to integrate climate risks into their land use planning and to improve their living conditions.

2.3.1 Introduction

The Indigenous population in Quebec lives in urban areas as well as in 56 communities (14 Inuit villages and 41 First Nations villages) located throughout the province (*see* Figure 2.3). Depending on their geographic location and the services available to them, Indigenous communities may be exposed to a variety of impacts that are caused or exacerbated by climate change (First Nations of Quebec and Labrador Sustainable Development Institute, 2015).

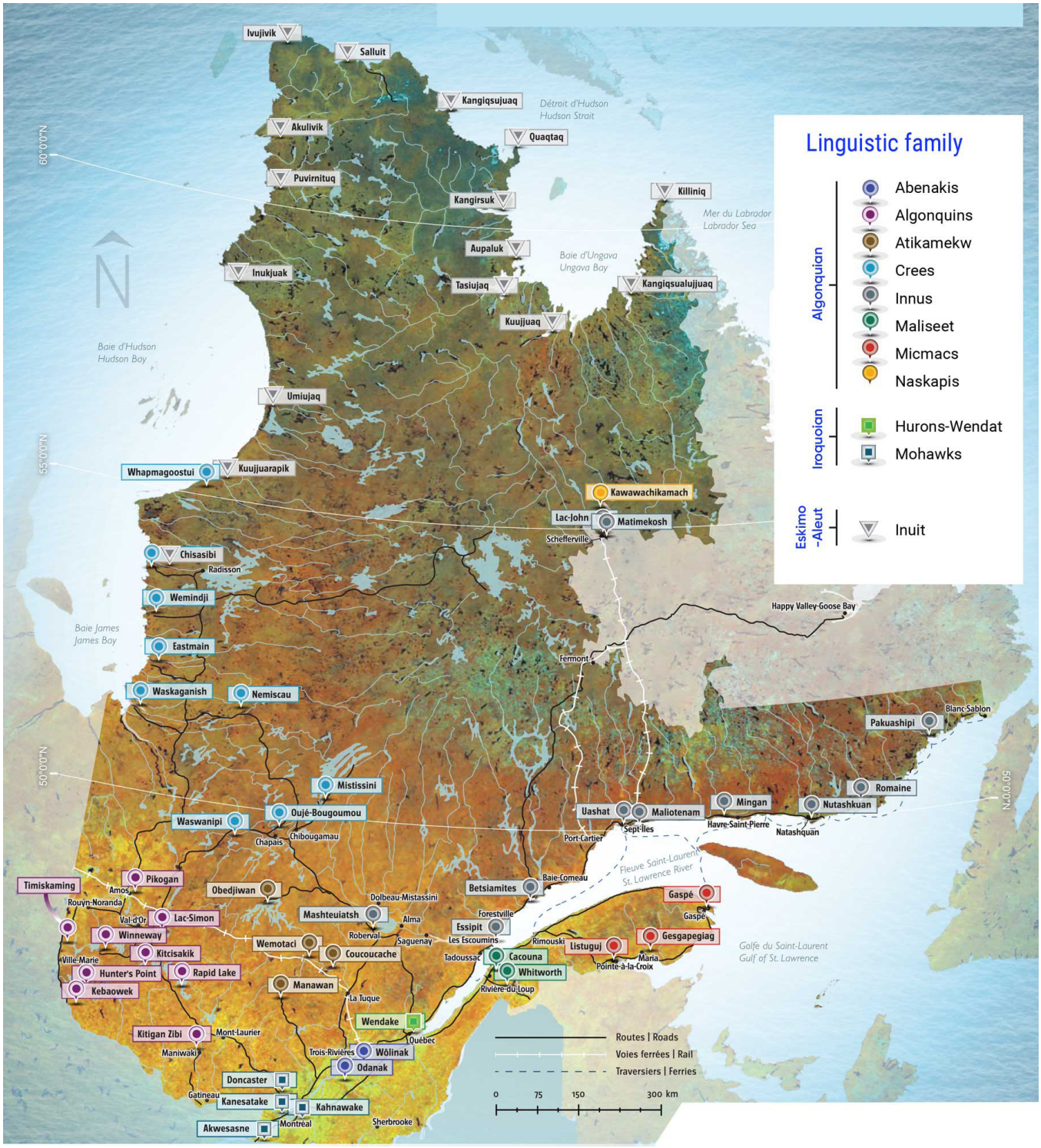


Figure 2.3: Map of the 11 Indigenous nations in Quebec. Source: Indigenous Services Canada, 2020

In addition to providing an overview of climate change issues, this section outlines adaptation measures for the different issues. It is important to keep in mind that implementing adaptation measures is still a major challenge for Indigenous communities in Quebec (Hennigs and Bleau, 2017). In addition to the difficulty of accessing funding (e.g., related to ineligibility for programs, tight deadlines for submitting applications, inadequacy of some programs in the Indigenous context, burden of accumulating accountability mechanisms), the implementation of adaptation initiatives is hampered by many competing priorities for community well-being in a situation of limited human resources.

2.3.2 Access to the land, mobility and safety

Across Quebec, access and travel for subsistence activities such as fishing, hunting and trapping are becoming less safe, mainly due to the reduction in the freeze-up period caused by the milder temperatures and more frequent winter thaws (Hennigs and Bleau, 2017; First Nations of Quebec and Labrador Sustainable Development Institute, 2017; Cree Trappers' Association, 2011). This causes significant disruptions in the practice of these activities.

Non-permanent winter trails that cross watercourses are less usable and must often be bypassed or abandoned for safety reasons (First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Cree Trappers' Association, 2011, 2010; Tremblay and Furgal, 2008). These changing winter conditions mean that Indigenous hunters, trappers and fishers can no longer rely solely on their traditional knowledge and on landmarks to predict weather conditions (Royer, 2016; First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Pearce et al., 2015). There has been an increase in the number and severity of accidents (especially snowmobile accidents) on water bodies that are not completely frozen (Cree Nation of Mistissini and Cree Nation Government, 2018; Downing and Cuerrier, 2011; Cree Trappers' Association, 2010).

For landlocked communities in Nunavik and on the Lower North Shore (Basse-Côte-Nord), access to subsistence resources and travel to neighbouring communities can also be hampered by unpredictable weather conditions (Tremblay and Furgal, 2008). This situation has significant implications for the mobility and traditional way of life of these communities. More urbanized communities also face challenges given the cultural importance of practices on the land for well-being and knowledge transmission (Grand Conseil de la Nation Waban-Aki, 2015a; First Nations of Quebec and Labrador Sustainable Development Institute, 2015).

In response to this situation, the Eenou community of Mistissini has outlined several measures in its *Climate Change Adaptation Action Plan* that are aimed at reducing the risk that these changes pose to the safety of the population, and to youth in particular. The measures set out in this plan include a coordinated program to monitor ice conditions, training to develop risk assessment skills for travel on frozen rivers and lakes, the development of new roads on dry land, and social networking to raise snowmobilers' awareness of the risks posed by unstable ice conditions (The Grand Council of the Crees, 2019; Cree Nation of Mistissini and Cree Nation Government, 2018). Many Indigenous hunters, fishers and trappers are already adapting their practices to make it easier to plan their travel and ensure their safety while travelling in the territory. These initiatives include the use of the global positioning system (GPS), satellite phones, rescue equipment and

community radio. Overall, this planning and the tools used help to reduce the risks that certain hazards pose to public safety (Clerc et al., 2011; Cree Trappers' Association, 2011; Larivière, 2011; Tremblay and Furgal, 2008).

For coastal communities in northern Quebec, travel on pack ice could also be hampered by the thinning of, and reduction in, the extent of the ice cover, as well as by the shortening of the ice season caused by rising temperatures. On the coast of Nunavik, the ice season, which generally takes place from November to May (Government of Canada, 2021), will be more than 6 weeks shorter by mid-century and more than 2 months shorter by 2100 (Hachem and Bleau, 2020). These changes will be compounded by an increase in extreme water levels by 2050 (Hachem and Bleau, 2020), resulting in coastal erosion and submersion problems. It should be noted that this trend may decrease by the end of the century due to local sea level fall in response to isostatic rebound of the Earth's crust in this region (Hachem and Bleau, 2020). The climate change impacts experienced by coastal Indigenous populations in the northern part of the province are similar to those in the coastal regions of eastern Quebec (*see* Section 2.5).

2.3.3 Permafrost thaw and land use planning

In Nunavik, communities are particularly sensitive to thawing permafrost, which may cause landslides, land subsidence or terrain slumping (Allard and Lemay, 2013; Jolivel and Allard, 2013). Since 1950, the southern limit of permafrost in Quebec has moved 130 km northward (Bouchard et al., 2014; Thibault and Payette, 2009) and this phenomenon is expected to continue in the region. Climate projections indicate an increase in extreme precipitation and winter rainfall, in addition to higher temperatures, which will result in accelerated thawing of permafrost (Vincent et al., 2017; Ouranos, 2015c).

Significant damage has already led to a revision of permafrost infrastructure design criteria, and various decision support tools have been developed to support knowledge transfer and integration (Shah and King, 2017). For example, maps showing building potential based on soil conditions and topography have been completed for all villages built on permafrost in Nunavik (Allard and L'Héreault, 2018; Allard et al., 2017, 2010). In practical terms, the maps can be used to identify unconsolidated deposits that are unstable and could lead to structural collapse (L'Héreault et al., 2013). They may also suggest construction techniques or maintenance practices that would be appropriate in the context of population growth.

With respect to the transportation sector, the ARQULUK northern engineering research program has developed solutions for permafrost infrastructure design and management, including a quantitative risk analysis tool that has the potential to improve climate change adaptation capabilities (Brooks et al., 2019; Lemieux et al., 2018). Some technological innovations have also been tested, one of which involves the use of fibre optics to monitor ground temperatures and detect early signs of permafrost degradation on the access road to the Salluit airport in the Nord-du-Québec region (Allard et al., 2017; Breton et al., 2017; Roger et al., 2015).

2.3.4 Food security

Although the problem of food insecurity seems to be decreasing according to the results of the 2015 First Nations Regional Health Survey (which does not include the Cree and Inuit), approximately one quarter of

Indigenous People are dealing with this problem, compared with about 8% of non Indigenous households in Quebec (Vinet-Lanouette and Godin, 2016; First Nations of Quebec and Labrador Health and Social Services Commission, 2015; Institut national de santé publique du Québec, 2014; Bernard and Duhaime, 2006). Due to the lack of access to hunting, fishing and gathering resources, some must turn to commercial foods, which are often less nutritious, costly and available only in limited quantities, particularly in remote areas (Vinet Lanouette and Godin, 2016; First Nations of Quebec and Labrador Health and Social Services Commission, 2015; Rodon and Natcher, 2014; Kuhnlein and Receveur, 2007; Bernard and Duhaime, 2006). In fact, research has shown a much higher incidence of diseases such as diabetes and obesity in Indigenous populations due to changes in diet and the scarcity of traditional foods (Hennigs and Bleau, 2017; Bergeron et al., 2015; Foro et al., 2013; Nieboer et al., 2013).

The scarcity of traditional foods is expected to increase with climate change. Indigenous Elders are already finding that ecosystems are being altered by the warming climate, which is having an impact on the distribution, abundance and health of subsistence species (*see* Case Story 2.1; Berteaux et al., 2018a; Lynn et al., 2013; Herrmann et al., 2012). For example, many hunters have observed the northward migration of some game animals, declining populations of native species and the arrival of new species (Cuerrier et al., 2015; First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Radio-Canada, 2015a; St. Regis Mohawk Tribe, 2013; Cree Trappers' Association, 2011). In northern Quebec, the abundance of salmonids, such as lake trout and Arctic char, which are important subsistence food sources, is likely to decline by the end of the century due to the loss of thermal refuges (cooler waters) caused by rising temperatures (Bélanger et al., 2017, 2013a).

Case Story 2.1: Ungava Peninsula Caribou Aboriginal Round Table

Migratory caribou, which are vital to the culture, spirituality and identity of Inuit, Naskapi, Innu and Cree communities, are currently experiencing dramatic declines (*see* Case Story 5.4 in Ecosystem Services chapter; Mallory and Boyce, 2017; Taillon et al., 2016). For example, the George River herd has declined by 99% since the 1990s; in the fall of 2018, there were only 5,500 caribou compared with an estimated 770,000 in 1993 (Ministère des Forêts, de la Faune et des Parcs, 2018a; Uashat mak Mani-utenam, 2017). Rising temperatures have contributed to the increased survival of predators, the spread of disease, the instability of the ice and the reduced availability of lichens. These impacts appear to alter the herds' seasonal migration patterns and exacerbate their northward range contraction (*see* Figure 2.4; Le Corre, 2016; Le Corre et al., 2016; Leblond et al., 2016; Taillon et al., 2016; Sharma et al., 2009). Some Cree hunters are adapting by replacing caribou with moose, whose presence is increasing in the James Bay area.

In an effort to ensure the recovery of this herd and the sustainability of caribou in the territory, seven Indigenous Nations demonstrated leadership in 2013 by creating the Ungava Peninsula Caribou Aboriginal Round Table (UPCART), a forum for more coordinated and long-term management of caribou. Following four years of negotiations, the seven Indigenous stakeholders came to a collaborative wildlife management agreement, including a long-term caribou management strategy that draws on Indigenous and scientific knowledge (Uashat mak Mani-utenam, 2017). In addition, government wildlife managers are tracking caribou migration patterns in real time using satellite tags, which helps support conservation decision making for the species.

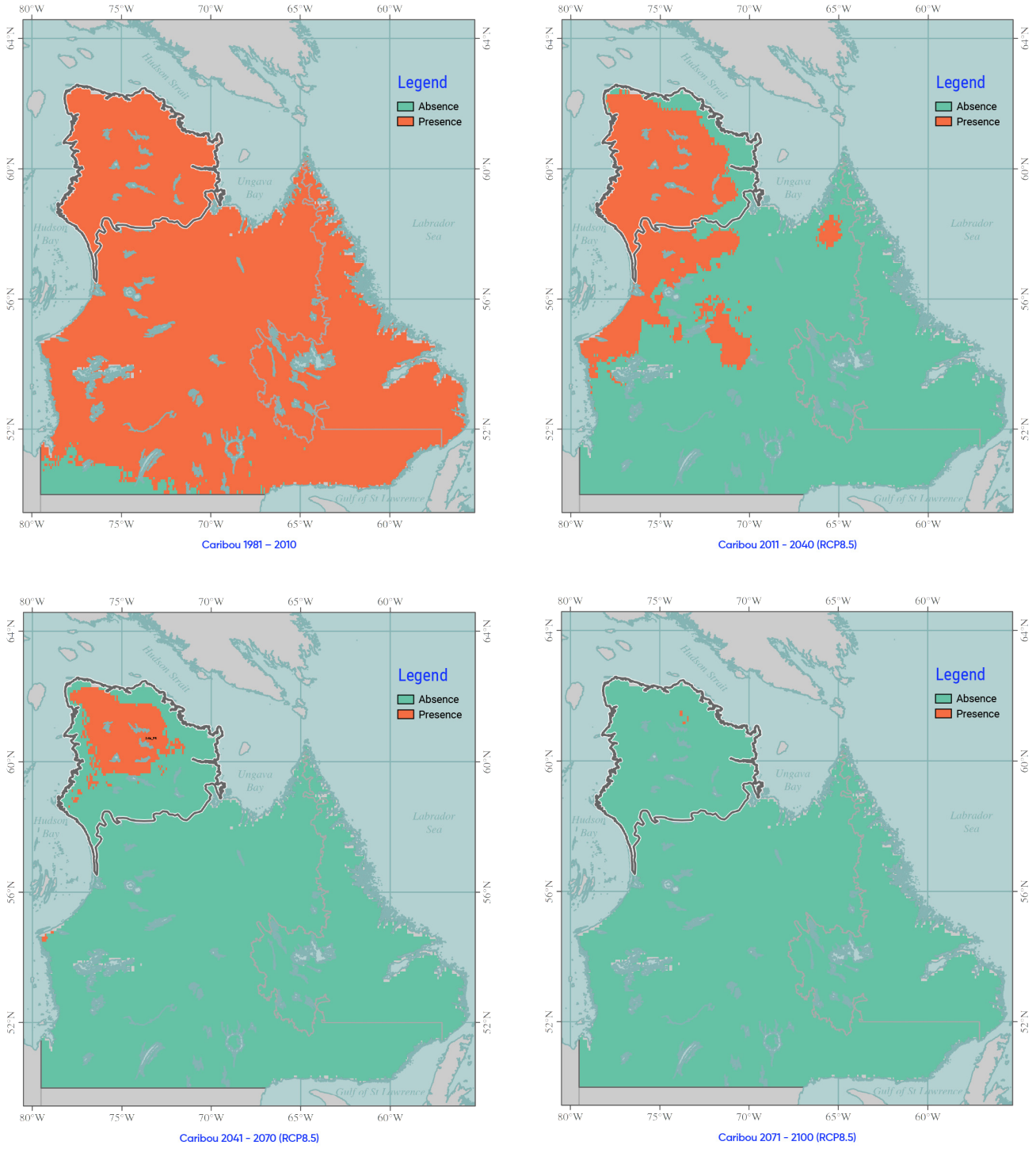


Figure 2.4: Reduction in range and numbers of migratory caribou. Source: Berteaux et al., 2018b – The Tundra Nunavik Project.

As the health of subsistence animals worsens due to habitat degradation and increased disease, the quality of meat from hunted and fished species is affected and the meat may sometimes become inedible. Communities have noted a reduction in fat levels, a higher rate of disease and parasites, and a change in the taste of the meat (Pétrin-Desrosiers, 2017; First Nations of Quebec and Labrador Sustainable Development Institute; Cree Trappers' Association, 2011). Some parasites or bacteria can be transmitted to humans, causing chronic and even severe bacterial infections, as is the case with furunculosis (*A. salmonicida*) and *C. Botulinum* toxins (Tam et al., 2011). In addition, preparing and consuming raw or fermented wild meat under warmer conditions increases the potential for the development and spread of zoonotic diseases and exposure to them (CBC News, 2017, 2016; Lowe et al., 2014; Simon et al., 2014a; Sampasa-Kanyinga et al., 2013; Campagna et al., 2011; Messier et al., 2009; Levesque et al., 2007). To prevent the transmission of these diseases, regional health agencies are organizing annual activities to educate hunters and their families on proper preparation and preservation of traditional foods.

Berries are also a part of the Indigenous diet and their consumption is beneficial for Indigenous People's health as they help to prevent chronic and cardiovascular diseases, such as diabetes and hypertension (Lynn et al., 2013). However, due to higher temperatures, berries in southern and central Quebec are often dry and less abundant (Cree Nation of Mistissini and Cree Nation Government, 2018; First Nations of Quebec and Labrador Sustainable Development Institute, 2015; St. Regis Mohawk Tribe, 2013; Cree Trappers' Association, 2011). In Nunavik, the increased presence of shrubs hinders the growth of berry species that are less shade-tolerant (Lemay, 2017; Lussier, 2017; Cuerrier et al., 2015; Myers-Smith et al., 2015; Paradis et al., 2014; Lavallée, 2013; McManus et al., 2012). In general, species that depend on intense sunlight (e.g., lingonberry, blueberry) will have more limited growth with increased shrub cover, while shade tolerant species (e.g., crowberry, cloudberry) may benefit from these new conditions (Lévesque et al., n.d.).

Dry conditions also affect the growth and availability of medicinal plants, limiting their production of essential oils. This reduces their healing potential and their use for medicinal purposes (First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Jacques, 2015). In the Eeyou Istchee James Bay region, extreme events and higher temperatures cause variations in the concentration of active phenolic compounds in Labrador tea, reducing its therapeutic properties (Rapinski et al., 2014). In other cases, medicinal plants have simply disappeared from ancestral territories and their harvesting must be done increasingly farther away from their traditional gathering places (First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Jacques, 2015).

Some pickers are adapting to the change in berry distribution by using social media to interact and learn about good picking locations (Desbiens and Simard-Gagnon, 2012). Furthermore, a growing number of communities see local agriculture as a complementary strategy for providing affordable fruits and vegetables, and are maintaining greenhouses, community gardens and even medicinal plant gardens. These initiatives can create a sense of local pride and empowerment while promoting economic development (Lamalice et al., 2016; Avard, 2015).

2.3.5 Maintaining cultural integrity and Indigenous knowledge

Just as the harvesting, preparation and sharing of subsistence foods contributes to the overall health of families and communities, so too does maintaining the integrity of their connection to ancestral lands. The impacts of climate change are therefore likely to cause a loss of cultural heritage for the Indigenous Peoples of Quebec (Bergeron et al., 2015; Laflamme, 2014; Simard-Gagnon, 2013). Berry picking, hunting and crafting are important pillars of a deeply rooted cultural and linguistic heritage, the varying expressions of which characterize the specific identity of each of these groups (Hennigs and Bleau, 2017; Bergeron et al., 2015; First Nations of Quebec and Labrador Sustainable Development Institute, 2015; Desbiens and Simard-Gagnon, 2012; Cree Working Group on the Plan Nord, 2011). Many Indigenous Peoples consider the health of the individual and their community to be based on the health of the natural environment (Brisson and Bouchard-Bastien, 2014; Adelson, 2000). Thus, climate change has the effect of severing this connection that is vital to cultural identity, knowledge transfer (Hennigs and Bleau, 2017; Pétrin-Desrosiers, 2017; Foro et al., 2013) and mental health (*see* Rural and Remote Communities chapter; Clayton et al., 2017; Cunsolo Willox et al., 2012; Hess et al., 2008; Albrecht et al., 2007; Basso, 1996). [Translation] "It's also a part of our culture that's at risk of disappearing with each species that goes away," said Jimmy Papatie, Algonquin of Kitcisakik.

Among the Abenaki, the making of black ash baskets, a valued cultural practice, is at risk of disappearing due to the emerald ash borer infestation, which has been exacerbated by climate change (Unpointcinq, 2018; Radio-Canada, 2017a; First Nations of Quebec and Labrador Sustainable Development Institute, 2015). Changes in land and land use are also leading to a loss of local expertise in the foundational knowledge of the land passed down through the ages (Foro et al., 2013; Downing and Cuerrier, 2011). Some of the ancestral terms (e.g., the names of the months among the Cree) used to describe the environment are no longer appropriate due to the shift in seasons and new weather phenomena associated with climate change (Laforest et al, 2018; UNESCO, 2017; First Nations of Quebec and Labrador Sustainable Development Institute, 2015). [Translation] "November is the month when we used to be able to walk without worrying about ice conditions, but that's not true anymore," said a member of the Whapmagoostui community (Laforest et al., 2018).

There are initiatives to address the decline in the transmission of Indigenous knowledge and practices. For example, in the Cree communities of Mistissini and Waswanipi, intergenerational gatherings organized on a regular basis include activities such as preparing traditional foods, learning about the use of medicinal plants and crafting (e.g., snowshoe and moccasin making, hide tanning) (Longchap and Bell, 2018; Laberge Gaudin et al., 2014).

To summarize, climate change is affecting many aspects of the lives of Indigenous Peoples in Quebec. Drawing on their traditional knowledge, values and worldviews, they are proposing innovative adaptation measures that are notable for their respect for the interdependence of human beings and nature. Their proposed measures are also forward thinking as they are based on a consideration of the aspirations and needs of future generations. In this sense, they are sources of inspiration and resilience for all societies, Indigenous or otherwise.

2.4 Urban environments are facing increasing climate hazards

Urban areas are grappling with significant health, public safety and environmental degradation issues that will worsen in the coming decades due to climate change. In Quebec, cities are home to most of the population and are faced with growing problems such as heat islands and stormwater management. A growing number of municipalities are developing adaptation plans and strategies to better cope with climate hazards.

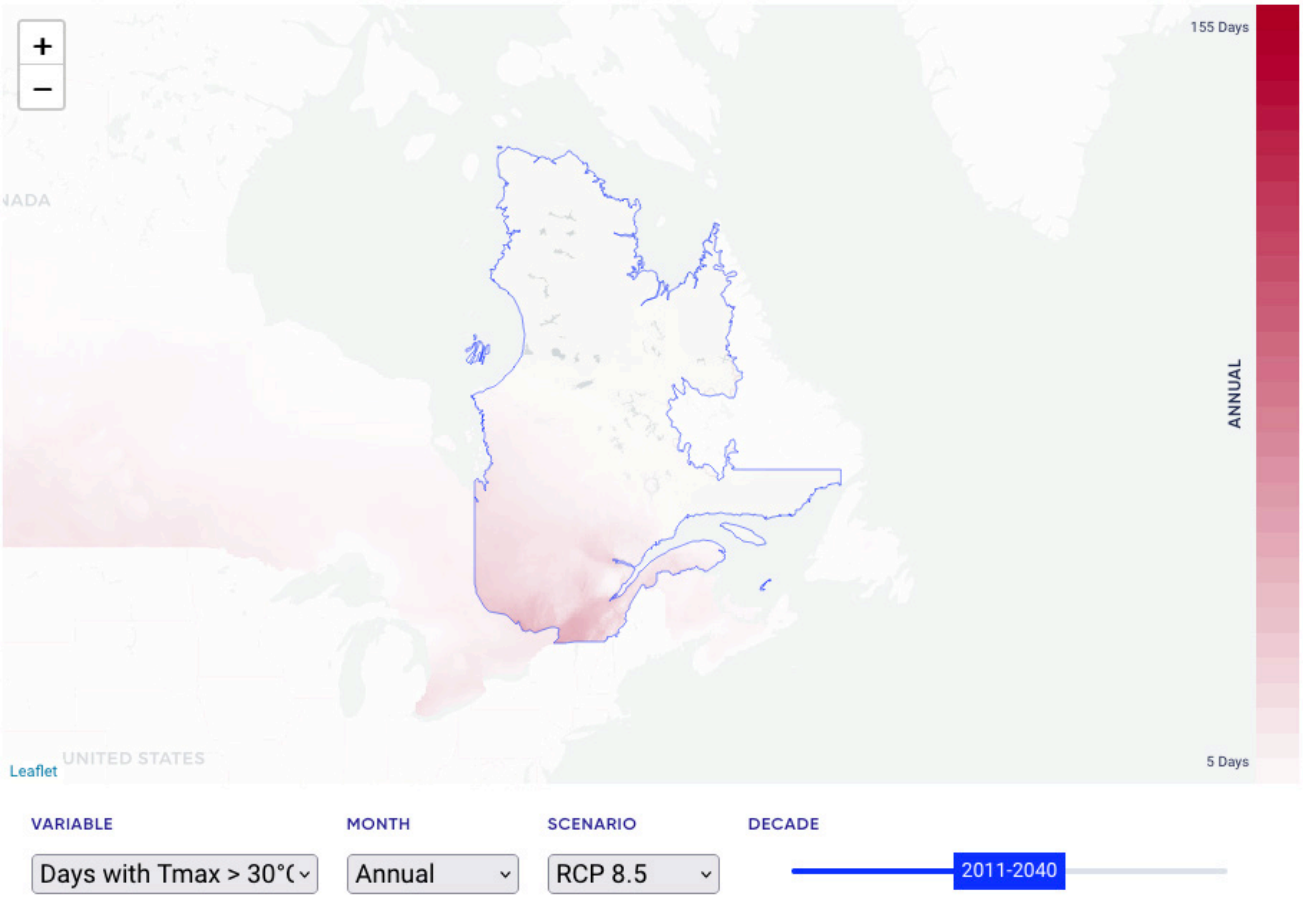
In Quebec's urban areas, populations face significant heat waves, and heavy rainfall events can overload sewage and stormwater management systems, in addition to causing wastewater overflows into the environment. Furthermore, urban sprawl is increasing and several practices that are associated with development, such as soil sealing, exacerbate the impacts of these climate hazards. Other hazards such as freeze-thaw cycles can also negatively affect building envelopes and infrastructure such as road surfaces. With climate change, these hazards are expected to intensify and to exacerbate the associated impacts. The protection of vegetated spaces, the implementation of green infrastructure, better stormwater management and the development of vulnerability analysis tools are just a few examples of measures that Quebec's urban communities are putting in place to adapt to climate change.

2.4.1 Introduction

Urbanized areas are home to nearly 80% of Quebec's population (Institut de la statistique du Québec (ISQ), 2020) and contain the infrastructure, buildings and equipment necessary for the production of material goods, the distribution of services and the consumption of goods that underpin socio-economic activities. Quebec has 10 cities that have more than 100,000 inhabitants; some of these cities are experiencing sharp rises in population growth rates and urban sprawl (Institut de la statistique du Québec, 2018a; Statistics Canada, 2016b). Cities are on the front lines of climate change because, in addition to having a significant role to play in reducing GHG emissions, they manage many of the consequences of climate change (*see* Cities and Towns chapter).

2.4.2 Extreme heat events

In Quebec, extreme heat events during the summer are expected to increase in duration and frequency (*see* Figure 2.2 and the portal *Portraits climatiques d'Ouranos* [Ouranos, 2018c] for additional figures; Ouranos, 2015b). In urban areas, the lack of vegetation, impervious surfaces, dark surfaces, urban morphology and anthropogenic heat, such as that emitted by vehicle engines, contribute to these events and promote the creation of heat islands (Sentenac, 2016; Environnement Canada, 2014; Bureau de normalisation du Québec, 2013; Collectivités viables, 2013; Anquez and Herlem, 2011; Institut national de santé publique du Québec, 2010; Giguere, 2009).



Snapshot of interactive Figure 2.2: Number of days with temperatures above 30 °C.

Over extended periods of time, extreme heat has many negative impacts on the health of populations (*see* Section 2.2). It promotes smog formation and degrades air quality, which is not always optimal in urban areas (Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2018; Schnell and Prather, 2017; Weichenthal et al., 2016; Kelly and Fussell, 2015; Kelly et al., 2012; Lebel et al., 2012). Above certain thresholds, these temperatures can also cause health problems such as heat stroke and dehydration, and are linked to higher mortality rates. This is especially true during heat waves when very high temperatures persist for several consecutive days and nights (Larrivée et al., 2015). The main vulnerable groups are older adults and younger individuals with pre-existing health problems, including mental health problems, as well as individuals living in disadvantaged environments (Bélanger et al., 2016, 2015; Smargiassi et al., 2009).

The metropolitan communities of Montréal and Québec City are where the main urban heat islands are found (*see* Figure 2.5; Ministère de la Sécurité publique du Québec, 2018a), but other cities that have dense downtown areas with little vegetation, such as Trois-Rivières, Sherbrooke and Gatineau, must also deal with this issue. In 2018, a heat wave in southern Quebec caused the death of about 100 people, most of whom were located in heat islands in Montréal (*see* Cities and Towns chapter; Lebel et al., 2019; Bélice, 2018; Direction régionale de santé publique CIUSSS du Centre-Sud-de-l'Île-de-Montréal, 2018).

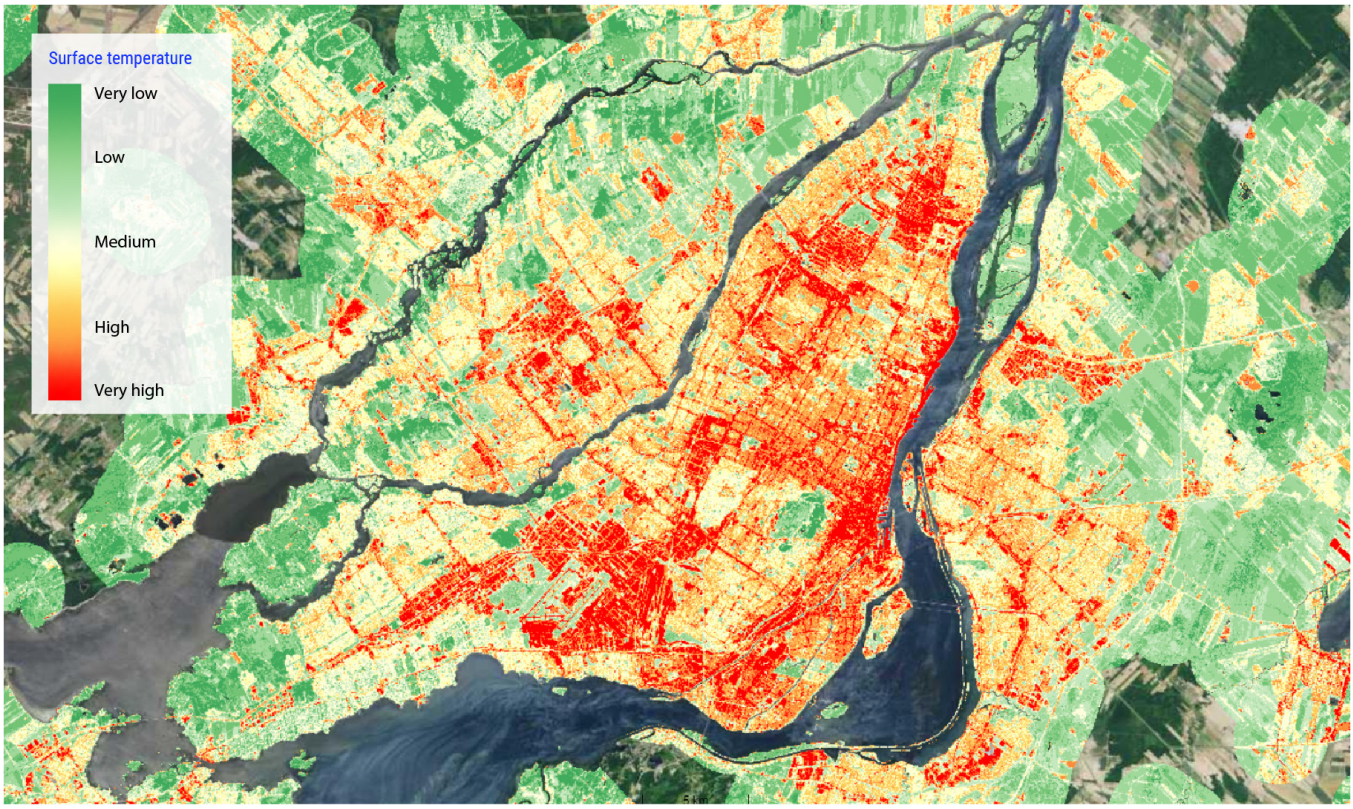


Figure 2.5: Map of heat islands in Montreal, Quebec. Source: Ministère de la Sécurité publique du Québec, 2018a.

2.4.3 Urban stormwater management

Climate change is projected to increase the frequency and intensity of extreme rainfall events, which can overload sewer systems and stormwater management and lead to wastewater overflows in urban areas (Ouranos, 2018c, 2015a, b; Tilmant et al., 2017; Mailhot et al., 2014; Sillmann et al., 2013; Monette et al., 2012).

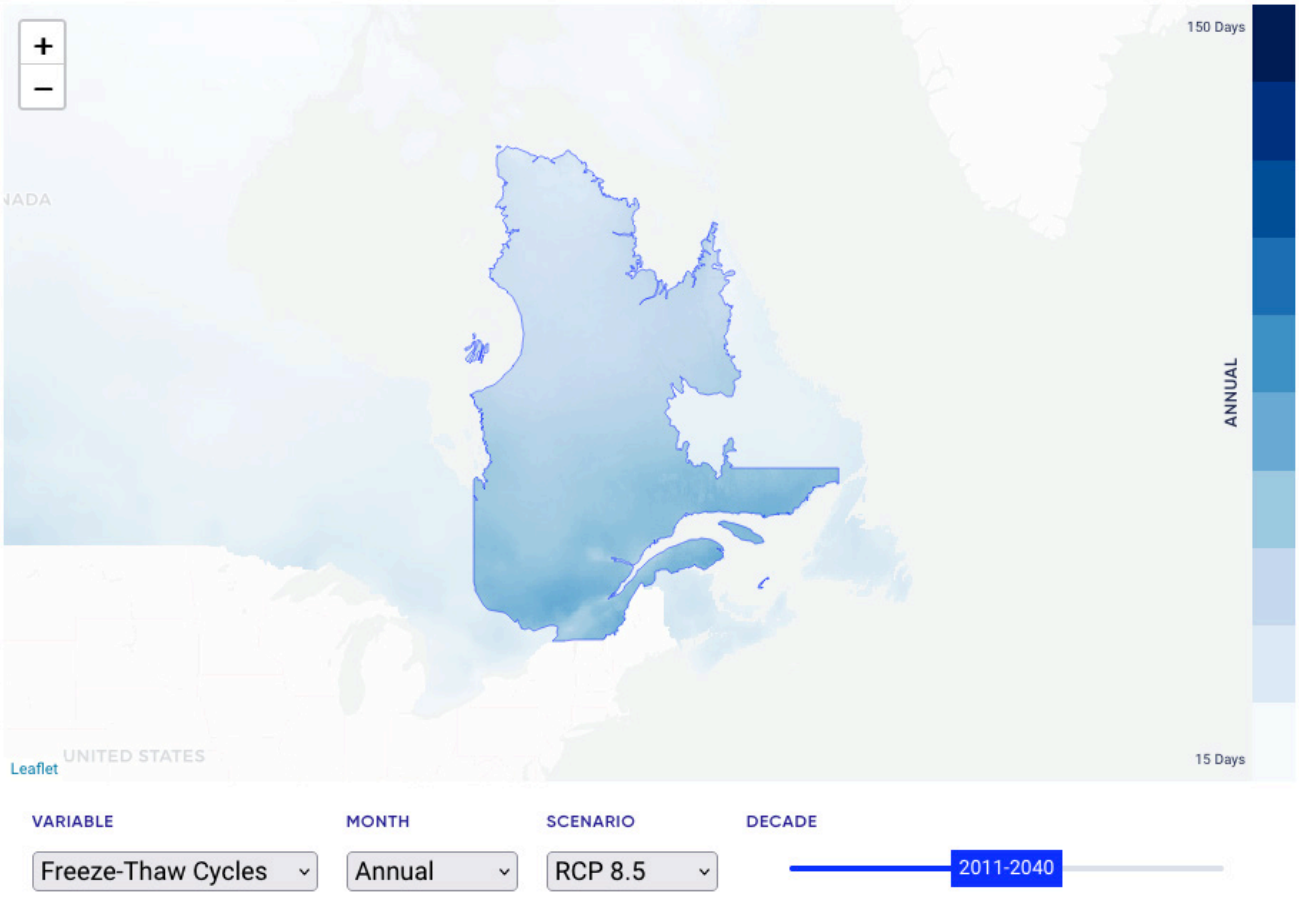
In recent decades, urban sprawl has resulted in a significant expansion in the area covered by impervious surfaces, thereby increasing stormwater runoff (Thomas and Da Cunha, 2017). Most cities still have sewer lines in their older areas that carry both stormwater and wastewater. For Quebec as a whole, this represents nearly 30% of the total length of the sewer network, while the percentage rises to nearly 70% in Montréal (Ville de Montréal, 2018c; Centre d'expertise et de recherche en infrastructures urbaines, 2017).

During heavy rainfall events, the capacity of the sewer network can be quickly overwhelmed, especially in downslope areas (Osseyrane et al., 2012). This can lead to flooding through overflow systems, sewer manholes and backups into residences (Mailhot et al., 2014; Ministère des Affaires municipales et Occupation du Territoire, 2014; Osseyrane et al., 2012). The floodwater can thus pollute public spaces, transportation infrastructure, buildings and water bodies near urbanized centres (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018; Thomas and Da Cunha, 2017).

Considerable volumes of water may be discharged in overflow events. For cities along the Great Lakes and St. Lawrence River, the volume of combined sewer overflows is already over 90 billion litres of raw sewage discharged annually (Mailhot et al., 2014). The contaminants typically present in these overflow waters, such as pathogens, metals, phosphorus, etc. (Ville de Montréal, 2018c), are harmful to aquatic and riparian ecosystems, and limit the use of these waters for public health reasons (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018; Jalliffier-Verne et al., 2017). For example, in times of heavy rainfall, the Saint-Charles River, which flows through Québec City, receives overflows with microbial contamination levels that make it one of the most polluted watercourses in Quebec. Despite the addition of retention ponds which have reduced the number of summer overflow events from 80 to four, as well as extensive bank naturalization work, use of the river for recreational purposes is prohibited because of the overflows that continue to adversely affect water quality (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018; Ville de Québec, 2018b).

2.4.4 Infrastructure issues

In addition to heat waves and intense precipitation, other climate variables such as freeze-thaw cycles during winter can prematurely alter building envelopes and structures and other infrastructure such as roadways (Dawson et al., 2018; Amec Foster Wheeler Environment & Infrastructure and Credit Valley Conservation, 2017; Olivry, 2012; Auld et al., 2007), creating public safety issues (Thomas and Da Cunha, 2017; Valiquette et al., 2013). Quebec is known for its potholes; they occur when pavement is infiltrated by water which freezes and expands, pushing up the pavement and giving rise to depressions and subsidence (Ville de Montréal, 2018a). This phenomenon is exacerbated by increasingly frequent winter thaws due to climate change (*see* Figure 2.2 and the portal *Portraits climatiques d'Ouranos* [Ouranos, 2018c] for additional figures) and is costly to municipalities. For example, in 2018, the City of Montréal filled in over 175,000 holes at a cost of over $3 million (Portail données ouvertes de la Ville de Montréal, 2018).



Snapshot of interactive Figure 2.2: Number of freeze-thaw cycles.

Buildings and infrastructures generally have a long life expectancy. Therefore, engineers and land use, urban planning and architecture professionals have a responsibility to consider climatic variations when adapting standards and criteria for building and other infrastructure design, building techniques, and asset management and maintenance practices (Association des professionnels de la construction et de l'habitation du Québec, 2018; Institute for Catastrophic Loss Reduction, 2018; Mailhot et al., 2018; Ministère de la Santé et des Services sociaux, 2017; Roy et al., 2017; Engineers Canada, 2016; Osseyrane and Kamal, 2012b; Auld et al., 2007).

2.4.5 Adaptive measures

In urban areas, the conservation of natural spaces and the integration of green infrastructure such as green streets and alleys, community gardens, green roofs, street trees and parks are seen as particularly promising adaptation measures (*see* Case Story 2.2 and Cities and Towns chapter). These measures address urban heat island issues by decreasing air temperature (Sentenac, 2016; Dubois, 2014; Environnement Canada, 2014)

and air quality issues (Dadvand and Nieuwenhuijsen, 2018; Franchini and Mannucci, 2018; Vergriete and Labrecque, 2007), in addition to helping to better manage runoff and filter pollutants (Petit et al., 2018). Such measures also provide many other benefits, such as increasing biodiversity, improving the living environment for better physical and mental health, and enhancing the aesthetic qualities and economic value of the environment in which they are implemented (Cloutier, 2018; Beaudoin and Levasseur, 2017; Revéret, 2017; Thomas and Da Cunha, 2017; Collectivités viables, 2013).

A number of greening initiatives led by citizens, community organizations and public stakeholders are taking place in Quebec cities (Cloutier, 2018), including the following: The Saint-Maurice Street Project (Le grand projet de la rue Saint-Maurice, *see* Case Story 2.2), Milieux de vie en santé (Nature Québec, n.d.), Interventions locales en environnement et aménagement urbain (ILEAU, n.d.), Attestation stationnements écoresponsables (Conseil régional de l'environnement de Montréal, n.d.) Vision de l'arbre de la Ville de Québec (Ville de Québec, 2016) Cultive ta ville (Laboratoire sur l'agriculture urbaine AU/LAB, 2021) and the Plan d'action canopée de Montréal (Ville de Montréal, Direction des grands parcs et du verdissement, 2012).

To combat heat islands, several communities, including Montréal, have also adopted by-laws promoting the use of more reflective roof coatings to limit the absorption of solar radiation (Ville de Montréal, 2016). An increasing number of cities in Quebec, such as Montréal, that are experiencing heat-related problems are adopting a response plan for extreme heat (Centres intégrés universitaires de santé et de services sociaux du Centre-Sude-de-l'Île-de-Montréal, 2018). Various adaptation measures in residential, commercial and institutional buildings are designed to ensure thermal comfort in hot and humid weather; examples of these measures are natural ventilation (opening windows), mechanical ventilation and air conditioning. Individual measures, such as hydration, showering and gaining access to cool places, whether inside or outside a building, are encouraged by the Institut national de santé publique du Québec (2016).

Effective stormwater management requires a variety of measures. Source control measures such as the disconnection of eavestroughs, bioretention systems and retention ponds are gradually being introduced in Quebec municipalities (Mailhot et al., 2018, 2014; Ministère des Transports, de la Mobilité durable et de l'Électrification des transports, 2017; Ouranos, 2015c; Dorner, 2013). In fact, it is mandatory in some cities and towns to disconnect eavestroughs from the sewer system (Ville de Drummondville, 2016).

Other measures, such as separating storm and sanitary sewer systems or resizing pipes and retention ponds, are sometimes necessary (Ministère des Transports, de la Mobilité durable et de l'Électrification des transports, 2017; Ouranos, 2015b). To install or extend storm sewers, certain calculation criteria established by the Quebec government must now be used when determining the dimensions of these structures. Based on these criteria, an 18% increase must be applied to precipitation intensities with return periods greater than two years to account for the impacts of climate change (Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2017a). A municipal assessment guide for sustainable stormwater management has been created to help municipalities understand the issue, raise awareness among the various stakeholders and promote good practices (Bleau et al., 2018; Regroupement des Organismes de Bassins Versants du Québec, 2016).

In the case of infrastructure, there are many possible adaptation measures. They vary according to the type of hazard and infrastructure. They may relate to the selection of materials as well as design, construction, operation, management, maintenance and rehabilitation practices (Mailhot et al., 2018; Institute for

Catastrophic Loss Reduction, 2018; Ministère de la Santé et des Services sociaux, 2017; Bureau de normalisation du Québec, 2013; Osseyrane and Kamal, 2012a). Some examples include matching foundation depths to ground frost depths (Association des professionnels de la construction et de l'habitation du Québec, 2018), ensuring that the building envelope prevents moisture from entering the structure and choosing materials that are resistant to repeated freeze-thaw cycles (Auld et al., 2007).

To select best practices for climate change adaptation, Engineers Canada proposes the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol. The tool first helps to assess the vulnerabilities and adaptive capacity of individual infrastructure elements over their entire life cycle (design, operation and maintenance) (Engineers Canada, 2016). These assessments then enable informed engineering decisions to be made about which components need to be adapted. Since its conception, the tool has been successfully used for several types of urban infrastructure and systems in a number of Quebec cities, including Montréal (Trépanier and Haf, 2015), Laval (Lamarre and Galarneau, 2011) and Trois-Rivières (Osseyrane and Kamal, 2012a). While access to specific climate data for the built environment remains limited (Roy et al., 2017), the tool helps to prioritize key risks for the systems under consideration and identify relevant measures to adapt them to changing conditions. These measures may include monitoring the condition of system components, training programs for operators and managers, and reviewing maintenance programs.

Under the *Environmental Quality Act*, projects subject to environmental assessment must now consider the potential impacts of climate change on the project, as well as the combined impact of climate change and the project on the receiving environment (Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2021c).

Lastly, Quebec municipal stakeholders have access to a database of nearly 500 resources (guides, reports, tools, methods, etc.) on all climate issues affecting the urban environment (Bleau et al., 2018). A guide to developing a climate change adaptation plan for municipalities is also available (Ouranos, 2010). Although most municipalities are in the early stages of adaptation (Valois et al., 2017b; c), a few have already developed and even adopted climate change adaptation plans and strategies (Thomas and Da Cunha, 2017), including Trois-Rivières (Ville de Trois-Rivières, n.d.), the Greater Montréal Area (Ville de Montréal, 2015), Laval (Ville de Laval, n.d.), Sherbrooke (Enviro-accès, 2013), Québec (Ville de Québec, 2018a), Rivière-au-Tonnerre (Beaulieu and Santos Silva, 2014) and the Indigenous communities of Odanak and Wôlinak (Grand Conseil de la Nation Waban-Aki, 2015b). Note that rural and remote populations and municipalities generally have more limited financial and human resources, which can complicate climate change adaptation in these settings (*see* Rural and Remote Communities chapter; Mehiriz and Gosselin, 2016).

Case Story 2.2: Saint-Maurice Street Project

A section of Saint-Maurice Street in Trois-Rivières was redeveloped to combat heat islands and reduce stormwater runoff (*see* Figure 2.6; *see* Case Story 2.6 in the Cities and Towns chapter). Curbside parking spaces were replaced with planting beds that capture and filter rainwater, and over 135 trees, 1,000 shrubs and 18,000 plants were planted. These measures are also intended to help recharge the water table, which is the main source of drinking water for a sector of the city (Ville de Trois-Rivières, 2018).

Figure 2.6 : Redevelopment project for Saint-Maurice Street in Trois-Rivières. Source : Ville de Trois-Rivières, 2018.

In recognition of the exemplary nature of this municipal achievement, the Association des ingénieurs municipaux du Québec awarded Trois-Rivières the 2018 Génie-Méritas prize (Ville de Trois-Rivières, 2018). A follow-up to this project, which was carried out between 2017 and 2018, measures the performance of green infrastructure amid climate change in terms of the quality and quantity of water leaving the infrastructure (Ouranos, 2017c).

2.5 Coastal areas of eastern Quebec are under increasing threat

The coastal areas of eastern Quebec face significant coastal erosion and flooding issues. These problems are exacerbated by the reduction in ice cover that amplifies the impact of storms. In view of the severity of the cumulative impacts on coastal environments, coastal populations in Quebec are making changes to their land development practices to adapt to climate change.

Climate change has altered freeze-up conditions and relative sea level in the Gulf and Lower Estuary of the St. Lawrence. This has exacerbated and will continue to exacerbate the impacts of winter storms by increasing coastal erosion and submergence. In light of the extent of the property damage and the environmental impacts, communities must manage their coastlines differently. Dismantling walls and riprap, rebuilding natural environments, relocating residences and banning construction along the coast are examples of measures implemented to adapt coastal environments to the impacts of climate change.

2.5.1 Introduction

Together with the Lower Estuary and the Gulf of St. Lawrence, eastern Quebec has a coastline that covers more than 3,250 km (*see* Figure 2.7; Bernatchez et al., 2015). The economic vitality and safety of the people who live there depend on the services provided by coastal ecosystems, such as beaches, barachois (a body of brackish water separated from the sea by a sand or gravel bar), lagoons and coastal marshes (*see* Ecosystem Services chapter). Communities also depend on critical infrastructure located in the coastal zone (national roads, ports, wharves, marinas, etc.), which supports major industries such as fishing, tourism and mining (Bourque and Simonet, 2008). The coastline of the St. Lawrence maritime zone is particularly sensitive to climate and hydrological hazards because of its geological nature.

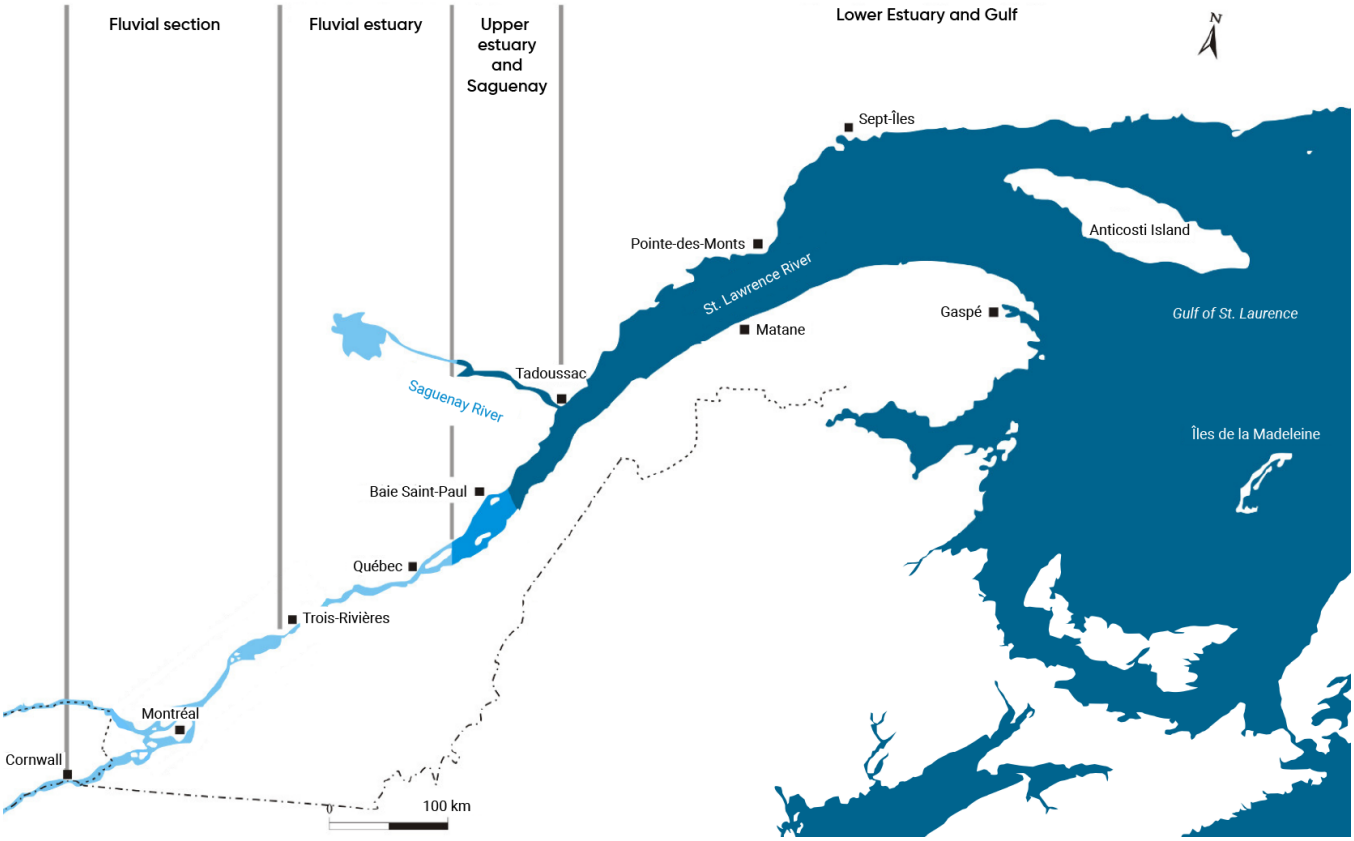


Figure 2.7: Fluvial section, Estuary and Gulf of St. Lawrence. Source: St. Lawrence Action Plan, n.d.

2.5.2 Reduction of ice cover

Due to warming temperatures, a reduction in ice cover and the freeze-up period has been observed in the St. Lawrence maritime area for several decades, and this trend is expected to continue (Galbraith et al., 2017). Consequently, the coasts are less well protected by ice and are more vulnerable to the onslaught of waves (Savard et al., 2008), especially storm surges. In 2016, a year of below normal ice conditions (Galbraith et al., 2017), the December 16 storm washed away a stretch of Route 132, isolating the village of La Martre, Gaspé, for three days (*see* Figure 2.8; Sûreté du Québec, 2016). These types of events (ice-free periods and storms) are already common in these regions,[1] but climate change could alter their frequency and intensity in the winter, thereby increasing their impacts (Senneville et al., 2014).

1 Examples of recent storms: December 30, 2016, on the Gaspé Peninsula; December 30, 2017, on the North Shore; November 29, 2018, in the Îles-de-la-Madeleine (Dubé, 2016; St-Pierre, 2017; Saint-Arnaud and Lowrie, 2018).

Figure 2.8: Sections of Route 132 washed away in La Martre, Gaspé. Source: Sûreté du Québec, 2016.

2.5.3 Increasing sea level, erosion and submergence

In addition to the decrease in ice cover, a rise in relative sea level is expected (James et al., 2014). Sea level increases will vary from one region to another (Savard et al., 2008), but will be more pronounced in certain areas such as the Îles-de-la-Madeleine, where submergence will be exacerbated by the fact that the islands are gradually sinking due to crustal subsidence[2] (Boyer-Villemaire et al., 2016).

On the other hand, the shoreline of the St. Lawrence maritime area as a whole is particularly susceptible to erosion due to its geological composition of unconsolidated and friable sedimentary rocks (Morneau et al., 2014). For example, in 2013, 50% of the coastline was eroding and 43% was at risk of submergence

2 Subsidence is a gradual sinking of the Earth's crust due to the deglaciation of the former ice sheet, named continental Ice Sheet (20-25,000 years ago). In some places it is more like uplift that is occurring (Atkinson et al., 2016).

(Bernatchez, 2015). Although average annual coastal recession varies by area, in some places it exceeds 1 m/yr (Chaire de recherche en géoscience côtière and Laboratoire de dynamique et de gestion intégrée des zones côtières, 2018). Erosion is quite significant on the North Shore, particularly in the territory of Uashat Mak Mani-Utenam, where it is accentuated by storm waves, landslides and a decrease in coastal ice (Bernatchez et al., 2012).

2.5.4 Impacts on infrastructure, populations and coastal ecosystems in eastern Quebec

Climate change could also have a variety of serious consequences for infrastructure (Circé et al., 2016c). For example, if no adaptation measures are implemented, more than 5,000 buildings and nearly 300 km of roads could be exposed to erosion by 2065 (Bernatchez et al., 2015; Larrivée et al., 2015). These consequences would lead to economic losses approaching $1.5 billion by mid century (Bernatchez et al., 2015), in addition to putting communities at risk of geographic isolation (Boyer-Villemaire et al., 2014; Drejza et al., 2014b).

Land transformation through deterioration of the landscape and its recreational use, damage to historical and cultural heritage, and loss of access to the sea result in decreased well-being and mental health (anxiety, insecurity, etc.) (Circé et al., 2016c; Lapointe et al., 2015; Boyer and Villa, 2011). In fact, riverside and coastal populations are more likely to experience significant psychosocial (e.g., post-traumatic shock, depression, etc.) and physical (e.g., cardiac, respiratory and skin problems) impacts from exposure to flooding, erosion and submergence (Saulnier et al., 2017; Vanasse et al., 2015; Lane et al., 2013; Alderman et al., 2012). Eastern Quebec is particularly at risk because it has an aging population and is less economically advantaged (*see* Section 2.2; Institut national de santé publique du Québec, Avenir d'Enfants and Québec en Forme, 2018). These changes could also cause a decline in tourism, marine industry activities and fisheries, resulting in significant revenue losses for the regions (*see* Box 2.1; *see* Case Story 2.3; Circé et al., 2016c).

Coastal ecosystems, which play a critical role in shoreline protection and water filtration, will also be impacted (Van and Faure, 2016; Bernatchez and Fraser, 2012). The combined effect of sea level rise and the presence of natural (e.g., cliffs) or human-made (e.g., roads, walls, riprap) barriers hinders the natural landward movement of the ecosystem, resulting in a loss of ecosystem area, a phenomenon referred to as coastal squeeze (*see* Ecosystem Services chapter; Bernatchez et al., 2016; Bernatchez and Quintin, 2016). Currently, 43% of coastal ecosystems in the Quebec maritime region have no setback because they are located within 5 metres of a barrier (*see* Figure 2.9). Thus, if no measures are put in place to offset the impact of coastal squeeze, it is estimated that 25% of the area of these ecosystems could be lost by 2060 (Bernatchez et al., 2016). In addition to contributing to coastal squeeze, human-made structures can also, depending on the type of coastline, cause increased erosion in areas adjacent to the structure, a phenomenon known as the "end effect" (Drejza et al., 2014a; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014a), and increase the vulnerability of the coastline to climate hazards (Bernatchez et al., 2008).

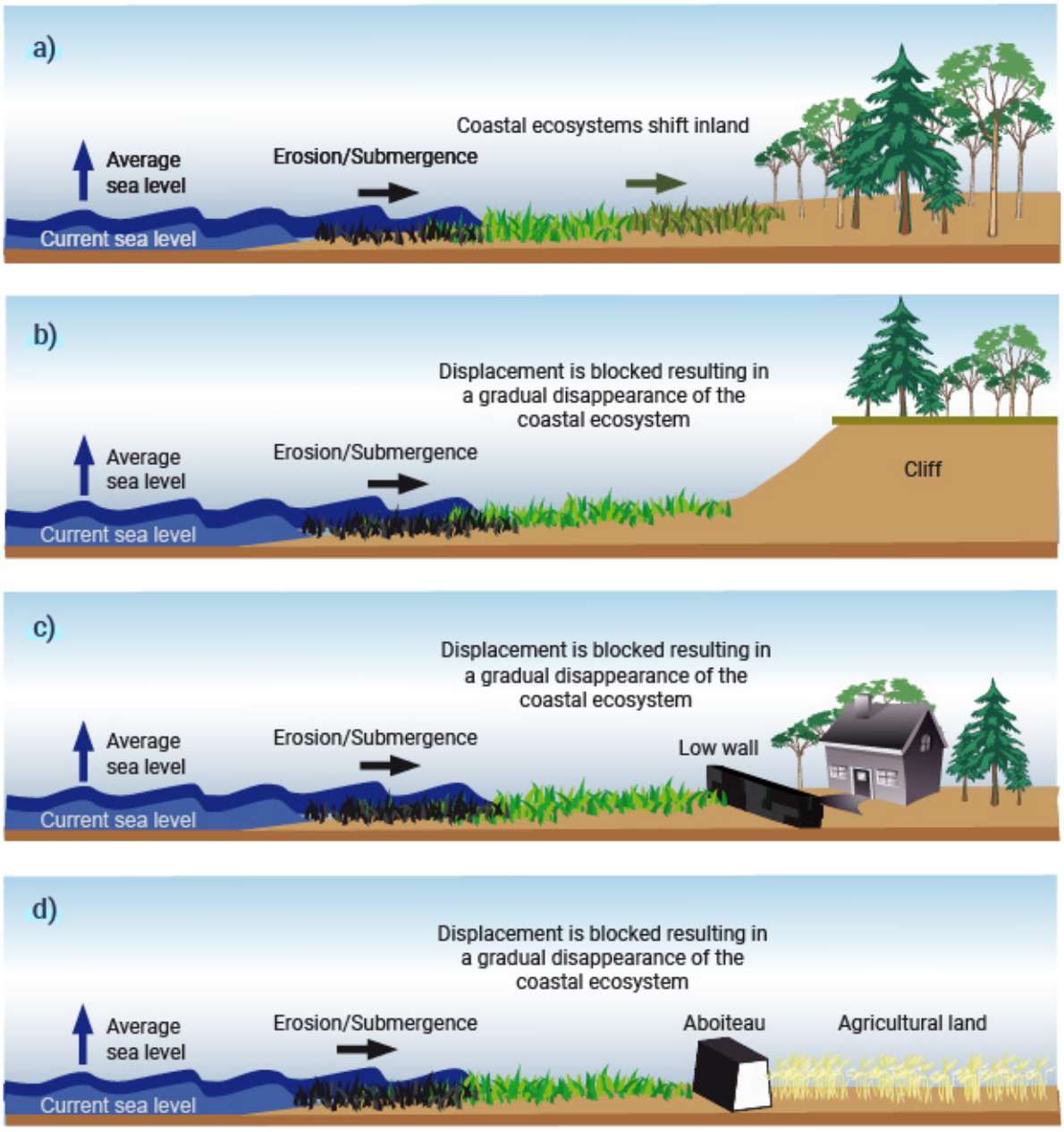


Figure 2.9: Diagram showing the factors that influence coastal squeeze. Source: Bernatchez and Quintin, 2016.

2.5.5 Adaptation measures

A range of adaptation measures can be implemented to reduce the impact of climate change in coastal environments (Circé et al., 2016c). The choice of measures should be based on the physical and human characteristics of the affected environments. Some options are referred to as non-structural and are categorized as soft methods because they are more in keeping with natural coastal conditions and dynamics. These options include the replenishment of beach sediment, shoreline revegetation (Bachand and Comtois, 2016; ZIP Îles de la Madeleine, 2014), conservation of coastal ecosystems (Bernatchez et al., 2016) and the relocation of homes along the coastline farther away from the waterfront (*see* the Ecosystem Services chapter; Paquette-Comeau, 2018).

For example, in Forillon National Park, work undertaken to naturalize the coast by dismantling 1.5 km of riprap and relocating a section of Route 132 has limited erosion (Parks Canada, 2018). In Sainte Flavie, the removal of about 50 homes located too close to a severely eroding shoreline was chosen as the best adaptation option. To avoid collateral damage to the vitality of the town and the mental health of its residents, the municipality also planned the development of a new housing project and hired a coastal resilience project officer to support the residents in this very emotional process (Paquette-Comeau, 2018). Furthermore, the Regional County Municipality (RCM) of La Mitis, of which Ste-Flavie is a part, adopted new by-laws in 2018 to limit the development of new construction in coastal areas (Ville de Métis-sur-Mer, 2018).

Box 2.1: Cost-benefit analysis of adaptation options

Cost-benefit analysis (CBA) is a method that compares the net benefits of each adaptation option against no action and ranks them according to their economic performance (Circé et al., 2016c). All impacts are taken into account, such as the loss of sea views or the deterioration of ecosystems. They all influence the cost-effectiveness of an adaptation solution at different time horizons (Da Silva et al., 2019). Results from five case studies in the Bas-Saint-Laurent, Gaspésie and Îles-de-la-Madeleine administrative regions reveal that it is often more cost-effective to act than to do nothing in almost all the sectors studied (Circé et al., 2016 a, b, d, e, f). As a result, CBA can be used to support decision makers when selecting adaptation measures (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter; Circé et al., 2016c).

The events of the first two decades of the 21st century (Quintin et al., 2013) underscored the urgent need to act and led to several local and Quebec maritime region governance initiatives (Chouinard et al., 2017; Noblet and Brisson, 2017; Boyer-Villemaire et al., 2015). These include support for municipalities along the St. Lawrence seeking to address coastal hazards through the Climate Change Action Plan 2013–2020 (Gouvernement du Québec, 2012), the St. Lawrence Action Plan 2011–2026 (St. Lawrence Action Plan, n.d.-b) and Avantage Saint Laurent, Quebec's new maritime vision (Ministère des transports du Québec, 2021). These initiatives also involve developing scientific knowledge, thanks in particular to the Laboratoire de

dynamique et de gestion intégrée des zones côtières (Université du Québec à Rimouski, 2017) and its major action research project, Résilience côtière, as well as the Ouranos consortium's projects, which contribute to a better understanding of the impacts of coastal hazards and provide municipalities with appropriate tools for dealing with them (Fraser et al., 2017; Marie et al., 2017; Beaulieu et al., 2015; Drejza et al., 2014b). Locally, stakeholders with organizations such as the ZIP (*zones d'intervention prioritaire* [areas of prime concern]) committees coordinated by Stratégies Saint Laurent, the Tables de concertation régionale [regional round tables], the Community-University Research Alliances, the Organismes de Bassins Versants [watershed organizations], the Nature Conservancy of Canada and many others, are actively involved in the integrated management and adaptation of the sea coast.

Case Story 2.3: Project for the protection and rehabilitation of the Anse du Sud shoreline in Percé, Quebec

In Percé, on the Gaspé Peninsula, the storms of December 30, 2016, and January 11, 2017, completely destroyed more than 200 metres of the already dilapidated Anse du Sud boardwalk (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2017). The extent of the damage prompted the Town of Percé to provide lasting protection for tourist infrastructure along the coast and in the centre of the city.

Percé initiated a process to protect and rehabilitate the coastline to make it more resilient to climate change. To help make this decision, a cost-benefit analysis (CBA) evaluated the cost-effectiveness of many possible development measures compared with a no-action scenario (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter). The CBA shows that if no action is taken, major damage or even destruction of coastal infrastructure could lead to total discounted losses of more than $700 million over 50 years, most of which would be attributable to a decrease in tourist traffic. Beach replenishment with pebbles was found to be the option with the most net discounted benefits amounting to approximately $770M over 50 years compared with taking no action (Circé et al., 2016b).

As a result, during the summer of 2017, more than a mile of beach was developed (*see* Figure 2.10). A new boardwalk and recreational and tourist facilities were also built to modernize the image of the downtown area and to preserve and even improve its tourist appeal (Ville de Percé, 2017).

Figure 2.10: Before and after photos of the Percé site. Source: © Steeve Morin and © Gwénaëlle Paque

2.6 Climate change impacts on water regimes, availability and quality

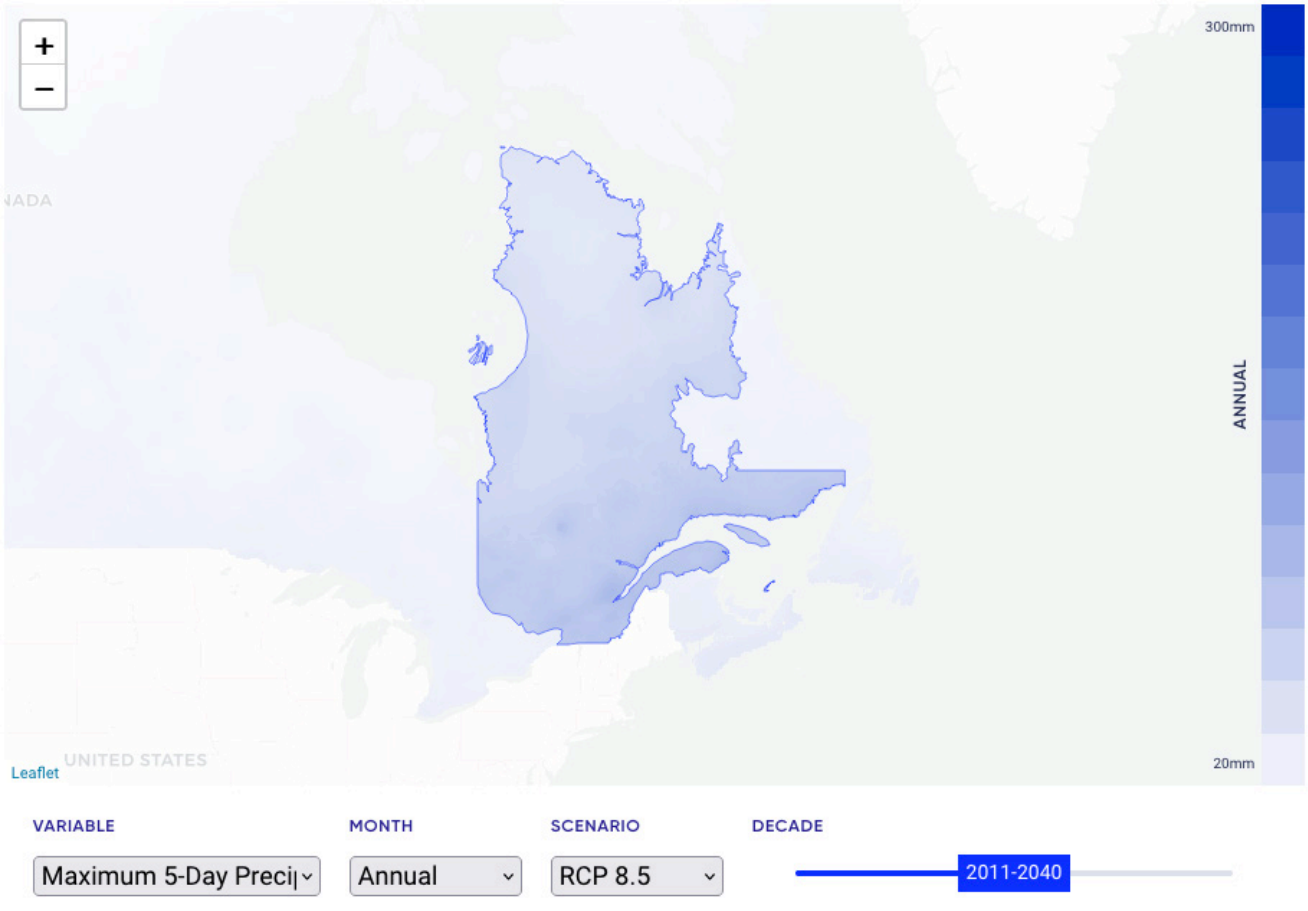
Quebec's lakes and rivers, including the St. Lawrence River, will be affected by climate change, which will modify water levels, flood risks, and water availability and quality. In response to potential changes in water regimes, Quebec is implementing adaptation measures, such as updating flood zone mapping, creating a flood forecasting system and protecting wetlands.

In the 21st century, it is projected that climate change will disrupt flood-related processes (rain, snow, snowmelt, etc.) and alter the flow regime of watercourses in Quebec. Depending on the physiography of the watersheds, these changes could alter the probability of flooding, which can cause extensive property damage, as well as health, psychosocial and economic impacts. Most Quebec municipalities have some portion of their territory bordering a watercourse, which exposes them to the risk of flooding. Furthermore, more severe low-water periods and their impacts on water quality could compromise drinking water supply, irrigation, navigation and hydroelectric production. Government and local stakeholders are now prioritizing these issues, and many tools are available to help prepare the public for greater variability in water levels.

2.6.1 Introduction

The thousands of bodies of water in Quebec represent 3% of the world's freshwater reserves (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018b). Diverse ecosystems and many human activities depend on these freshwater resources, a situation that points up the critical importance of appropriate water management (*see* Water Resources chapter; Lachance-Cloutier et al., 2015).

The hydrological regimes of rivers in southern Quebec will be subject to more frequent winter thaws, increased rainfall in winter and spring, and more intense extreme rainfall events in summer and fall (*see* Figure 2.2 and the portal *Portraits climatiques d'Ouranos* [Ouranos, 2018c] for additional figures; Ouranos, 2018c, 2015a, b; Tilmant et al., 2017; Sillmann et al., 2013; Mailhot et al., 2012; Monette et al., 2012). By 2050, higher average flows during winter are predicted, as well as an earlier spring freshet (Lachance-Cloutier et al., 2018). On the other hand, more severe low-water periods in summer and more intense high flows in summer and fall are expected to occur in a large portion of southern Quebec (Lachance-Cloutier et al., 2018; Tilmant et al., 2017; Ouranos, 2015b).



Snapshot of interactive Figure 2.2: Maximum five-day cumulative precipitation (in mm).

2.6.2 Flooding

The predicted hydrological changes could influence the recurrence and intensity of both open-water flooding (Lachance-Cloutier et al., 2018; Ouranos, 2015b) and ice jam flooding and ice breakup during the winter (Turcotte et al., 2020; Thomas et al., 2012), as well as flooding due to sewer backups (*see* Section 2.4).

These are recurring phenomena in Quebec (Mayer-Jouanjean and Bleau, 2018; Ouranos, 2018c) as many municipalities are located along a watercourse and even built in known flood zones (Thomas et al., 2012). In fact, the 2010s were marked by a series of flood disasters in several Quebec communities (Le Journal de Montréal, 2019; Gouvernement du Québec, 2018a; CNW Telbec and Ministère des Affaires municipales et de l'Occupation du territoire, 2017; Ministère de la Sécurité publique du Québec, 2017; Gouvernement du Québec, 2013) which had significant material, social, health, psychological and economic consequences (Généreux et al., 2020; Bustinza and Gosselin, 2014; Thomas et al., 2012; Maltais et al., 2000).

These floods affect buildings and infrastructure, some of which are critical, particularly in urban areas where impacts are typically exacerbated by dense populations and concentrated socio-economic activities (Thomas et al., 2012; Saint-Laurent and Hähni, 2008). The direct damage caused by these hazards represents significant costs, approximately $70M/year for the Quebec government during the 1991–2013 period (Larrivée et al., 2015). This does not include the indirect damage related to the decrease in the property value of affected properties and the impact on municipal taxation (Ville de Laval, 2017). More recently, following the 2017 floods, the Quebec government had to disburse nearly $360M in financial assistance (Ministère de la Sécurité publique du Québec, 2021). These costs could increase due to the combined impact of climate change and future land use choices.

2.6.3 Water availability and quality

Although the drinking water distributed in Quebec is generally of excellent quality (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014a), surface and ground water could be affected by more severe low flows which will limit their dilution capacity (Rondeau-Genesse et al., 2016; Ouranos, 2015b). Such a situation would compound anthropogenic pressures such as industrialization, urbanization, agricultural activities, resort development and the absence or inadequacy of wastewater treatment systems which have caused a deterioration in water quality over the years (*see* Water Resources chapter; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014b).

More severe low flows could also compromise the supply of water for agricultural and industrial use, river navigation, hydroelectric generation and various recreational activities (Ouranos, 2015b). In addition, these lower flows could affect the catchment capacity of a number of treatment plants which require a minimum level of inflows in order to produce drinking water (Foulon and Rousseau, 2018; Chan et al., 2015) and they could alter groundwater flow and recharge patterns (Ministère de l'Environnement et de la Lutte contre les changements climatiques., 2017b).

Meanwhile, rising temperatures could promote the growth and proliferation of algae such as toxic cyanobacteria in eutrophication-prone environments, as well as pathogens such as *Escherichia coli*, thereby contaminating drinking water sources and creating a public health issue (Jalliffier-Verne et al., 2017; He et al., 2016; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014b; Zhang et al., 2012; Bird et al., 2009).

2.6.4 The St. Lawrence River

The St. Lawrence River is an iconic feature of the hydrographic landscape of Quebec. More than 80% of Quebec's population lives in the St. Lawrence River valley (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018c) and more than 75% of Quebec's industries are located along the river (Comtois and Slack, 2015). Its river system drains 25% of the world's freshwater supply (Government of Canada, 2017), and it is the source of drinking water for nearly one third of Quebecers (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d; Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2017b).

Over the next few decades, climate change may affect net water supplies to the Great Lakes and, as a result, may affect water levels in the St. Lawrence River (Larrivée et al., 2016; Music et al., 2015). Given the hydrological complexity of this system, considerable uncertainty remains regarding projections of the impacts of climate change on the Great Lakes water balance. Nevertheless, an increase in the frequency of low-water events in late summer and fall is anticipated (Music et al., 2015).

Decreases in inflows of water to the fluvial section of the St. Lawrence could have impacts on its ecosystems and on the economic activities that depend on them, such as fishing (He et al., 2016; Larrivée et al., 2016; Working Group on the State of the St. Lawrence Monitoring, 2014), commercial and recreational navigation (Comtois and Slack, 2016; Bleau et al, 2015a; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014a), hydroelectric production (Desjarlais and Da Silva, 2016), drinking water supply and recreational activities (Larrivée et al., 2016; Chan et al., 2015). Decreased flows could also reduce the attractiveness of some riverside properties and thus affect their property value (Özdilek and Revéret, 2015).

2.6.5 Adaptation measures

Maps are important tools for raising awareness, and for emergency management, land use planning and decision support (Ouranos, 2018c; Thomas et al., 2012). Some initiatives have been undertaken to map flood vulnerability, such as the creation of an atlas of vulnerability to climate hazards in Quebec (Barrette et al., 2018).

However, the events of 2017 revealed that the mapping of flood-prone areas was incomplete, sometimes outdated and not standardized in most regions of the province, a situation that limits adaptation potential (Corriveau et al., 2019). A major effort to update flood mapping was initiated following these disasters by several municipal agencies such as the Montréal Metropolitan Community (Communauté métropolitaine de Montréal), the Québec Metropolitan Community (Communauté métropolitaine de Québec), the City of Gatineau, and several RCMs (Ministère des Affaires municipales et de l'Habitation du Québec, 2019). The Quebec

government also launched the INFO-Crue project, which will provide tools for delineating flood-prone areas in a large part of southern Quebec while taking climate change into account, and will develop mapping to forecast floods over several days, as well as tools for land-use planning (Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2019).

A significant number of residents in flood-prone areas are unaware of the risk they face (*see* Water Resources chapter; Thistlethwaite et al., 2017). Those who are aware,are more likely to engage in preventive behaviours when financial assistance is available and when they are educated about the potential impact on their health (Valois et al., 2017e; Poussin et al., 2014; Kellens et al., 2013; Bubeck et al., 2012). The Quebec government increased its outreach efforts to citizens, municipalities and regional stakeholders following the major floods in 2011, 2017 and 2019 (Gouvernement du Québec, 2018a; Ministère de la Sécurité publique du Québec, 2018b, 2014). In addition, financial assistance programs have been enhanced in order to support the implementation of protection and relocation measures for people living in flood-prone areas (Ministère de la Sécurité publique du Québec, 2021; 2018b). These investments in risk prevention and management are in addition to existing tools such as the flood monitoring program *la plate-forme d'alerte Vigilence* and the Chaudière River monitoring system (Ministère de la Sécurité publique du Québec, n.d.; COBARIC, n.d.).

With regard to water quality issues, several preventive measures can be considered, such as initiatives to protect source water. One example of such an initiative is the Quebec strategy to protect and conserve drinking water sources [Stratégie de protection et de conservation des sources destinées à l'alimentation en eau potable] (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2012). Quebec's program for monitoring the quality watercourses, the *Regulation respecting the quality of drinking water*, and various early warning tools and preventive measures, such as boil water advisories are mechanisms that are used to deal with water quality degradation and associated public health issues (Ministère de l'Environnement et de la Lutte contre les changements climatiques du Québec, 2021a). In addition, the Quebec government recently adopted the Quebec water strategy, which is aimed at ensuring more effective prevention and management of water-related risks (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d).

Land use planning is an essential part of managing water issues. For example, when this planning takes risk levels into account, it can be used to restrict development in flood-prone areas and in river mobility zones and reduce public vulnerability and exposure (Ouranos, 2018b; Thomas et al., 2018; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2015; Boyer and Roy, 2013; Biron et al., 2013). Following the 2019 floods, the Quebec government established a special intervention zone in which it imposed a moratorium on new construction and on the reconstruction of buildings destroyed by floods until such time as a new flood zone management framework has been developed and implemented by municipalities (Ministère des Affaires municipales et de l'Habitation, 2019).

Another approach involves the conservation of wetlands that can help temporarily store floodwaters, regulate flows, and trap pollutants that would otherwise enter lakes and watercourses (Biron, 2015; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2015; Fournier et al., 2013; Olar et al., 2013). Wetland conservation in the province is governed by the *Regulation respecting compensation for adverse effects on wetlands and bodies of water*, as well as by a law on the conservation of wetlands and bodies of water that amends five other laws, thus emphasizing the special character of these environments (Ministère de l'Environnement et de la Lutte contre les changements climatiques du Québec, 2021b).

These measures provide co-benefits and avoid major investments associated with emergency management and structures such as dikes, dams, riprap and other bank protection and stabilization works, etc. (IPCC, 2014b; Olar et al., 2013). Such measures are questionable since they may amplify shoreline erosion and provide a false sense of security as they do not completely eliminate the risk (Ouranos, 2018c, 2015b; Morneau et al., 2014; Lake Champlain Basin Program, 2013).

Like many countries and other Canadian provinces, Quebec is implementing integrated watershed management (Cloutier, 2018; Ministère du Développement durable de l'Environnement et de la Lutte contre les Changements Climatiques, 2018 a, c; Pelletier, 2017; Canadian Council of Ministers of the Environment, 2016). Under a water management master plan, Quebec's watershed organizations share responsibility for managing watersheds in the province in 40 zones. This approach is aimed at mobilizing the various stakeholders that deal with water issues, such as municipalities, RCMs, citizens and private users, and having them work together to preserve and improve water quality, as well as reduce water-related risks and damage such as flooding (Comité de concertation et de valorisation du bassin de la rivière Richelieu, n.d.; Regroupement des organismes de bassins versants du Québec, 2018a). Although integrated watershed management is considered essential for sound water and land management, Quebec's watershed organizations do not have decision-making authority. They play more of an awareness-raising and consensus-building role (*see* Box 2.2; Milot et al., 2015). Collaboration among the different stakeholders involved in water management and land use planning is crucial for ensuring the success of adaptation measures (*see* Case Story 2.4; Baril et al., 2020; Therrien et al., 2019).

Box 2.2: La RésAlliance

RésAlliance is a Quebec community of practice dedicated to climate change adaptation and is led by the Regroupement des organismes de bassins versants du Québec [association of Quebec watershed organizations]. It was created in response to the 2017 flooding events to provide a forum for knowledge transfer and sharing experiences between communities that need to adapt to new climate realities affecting water management. It offers an adaptation approach, peer-based learning and a set of tools including a list of best practices, as well as webinars (Regroupement des Organismes de Bassins Versants du Québec, 2018b).

Integrated management of the St. Lawrence River is implemented in keeping with the objectives of the Quebec Act "to affirm the collective nature of water resources and to promote better governance of water and associated environments", and it aims to strengthen its protection (Ministère du Travail, de l'Emploi et de la Solidarité sociale, 2021). This approach is achieved partly through the annual St. Lawrence Forum and the regional round tables (several of which are coordinated by ZIP committees), which bring together regional stakeholders involved in managing resources and uses of their respective areas of the St. Lawrence and help implement the St. Lawrence Action Plan 2012–2026 (St. Lawrence Action Plan, n.d.-a). The Plan is aimed at reducing pollution, protecting human health, conserving, restoring and enhancing wildlife habitat, encouraging sustainable navigation practices and engaging communities (Gouvernement du Québec and Government of

Canada, 2011). The Great Lakes and St. Lawrence Cities Initiative is also addressing these adaptation issues (Great Lakes and St. Lawrence Cities Initiative, n.d.).

Case Story 2.4: Flood adaptation governance experiment in the Municipality of Saint-Raymond, Quebec

The Sainte-Anne River has overflowed its banks in downtown Saint-Raymond, Quebec, approximately 70 times since 1893. This corresponds to a flood about once every two years (Cloutier, 2018; Ville de Saint-Raymond, 2018). Most of the town is located on either side of the river, and nearly one third of its urban perimeter is in a flood zone (Cloutier, 2018).

A flood caused by an ice jam in 2014 raised the water level in the river to record highs, resulting in extensive damage (*see* Figure 2.11; Ville de Saint Raymond, 2018; Thomas, 2017). This flood was the catalyst for the creation of a collaborative river management committee (Comité Rivière), which brings together elected officials, municipal service directors, residents and representatives of the local watershed organization (Cloutier and Demers, 2017). The committee's goal is to reduce the risk of flooding through the implementation of a water management master plan. It has joined with a panel of government and academic experts who are working to improve knowledge of watercourses in winter and flooding due to ice jams (Morse and Turcotte, 2018, 2015), and helping to assess the vulnerability of the municipality (Thomas, 2017) to identify practical ways to improve public preparedness.

Figure 2.11: Ice jam flooding on the Sainte-Anne River in Saint-Raymond, Quebec. Source: The Canadian Press/ Jacques Boissinot, 2012.

Prevention activities have been conducted on the river for over a century (Lagadec, 2017). More recently, the river committee has accelerated the implementation of new measures such as installing a floating boom upstream of the downtown area to prevent the excessive accumulation of ice crystals (frazil), which could lead to the formation of ice jams in this vulnerable location. This measure has been coupled with the injection of warm water and the use of machinery to weaken the ice cover (Morse and Turcotte, 2015). Additional interventions could be implemented, such as modifying the Chute-Panet Dam to improve flow management (Ville de Saint-Raymond, 2018).

The municipality of Saint-Raymond now offers real-time information on the state of the river (Les OBV du Québec, 2017) as well as a public warning system (Ville de Saint-Raymond, n.d.) in case of flooding. A committee of volunteers is also available to support and guide disaster victims during a flood.

The entire process has allowed for the development of a risk culture and the community spirit necessary for resilience, and this has made St. Raymond a leading player in RésAlliance (Regroupement des Organismes de Bassins Versants du Québec, 2018b). Several residents have adapted their behaviour and are making changes to their homes by installing pumps in their basements, or even moving their belongings in the lead-up to winter (Les OBV du Québec, 2017).

2.7 Ecosystem services play an important role in adaptation

Quebec's population relies on services provided by ecosystems to adapt to climate change. However, Quebec's ecosystems are themselves impacted by climate change. Several methodologies and tools for monitoring biodiversity have been developed to support decision-making in order to improve the conservation of ecosystems and maintain the ecological services they provide.

Climate change such as rising temperatures and changing precipitation patterns are impacting ecosystems in Quebec. Climatic conditions are becoming more favourable for a wide variety of species from farther south, some of which are invasive. Existing species ranges are also changing, leading to a disruption in the structure and functioning of ecosystems that have already been weakened by anthropogenic pressures. Integrating ecosystem conservation into decision making in all economic sectors is important in order to maintain ecological services. Some key economic sectors are dependent on vital ecosystem services.

2.7.1 Introduction

According to the definition in the Convention on Biological Diversity (United Nations, 1992), biodiversity is the "variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other

aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." It plays an essential role in the functioning of ecosystems on which human beings depend for provisioning, regulating and sociocultural services (*see* Ecosystem Services chapter; Díaz et al., 2018).

In Quebec, this natural capital is likely to change due to the cumulative impacts of human development as well as climate change. Since Quebec has a wide variety of ecosystems, these impacts will vary from one region to another. This situation complicates the management of the territory and adaptation to climate change.

2.7.2 Shift and contraction of ranges and bioclimatic niches

In Quebec, climate change is causing a northward migration of many plant and animal species. On average, bioclimatic niches in Quebec could shift about 45 km per decade, which is extremely fast (Berteaux et al., 2014). This can cause ecological imbalances and public health issues. For example, the range of the red fox now extends beyond the 55th parallel due to warmer temperatures and human activity (Simon et al., 2014a). This increases the risk that the rabies virus, whose primary host is the Arctic fox, will spread to the red fox and other animals, including domestic animals, as well as to humans (Simon et al., 2014a). Meanwhile, some native species, especially trees and other plants, will not be able to keep up with the geographic shift of their bioclimatic niches, which will move more than 500 km northward by the end of the century (Berteaux et al., 2018b; 2014). As a result, 5% to 20% of forest habitats (*see* Section 2.9.3) could become unsuitable for various tree species over the course of the century, leading to significant changes in the composition and functioning of Quebec's forest ecosystems (*see* Figure 2.12; Boulanger et al., 2017; Périé and de Blois, 2016). Some of the more vulnerable plant and animal species (those that have small populations, a fragmented distribution, or low fecundity, or that are already in decline) will not be able to adapt to the new conditions and may become extinct (Auzel et al., 2012), particularly at the northern limits where they do not have the ability to migrate further north.

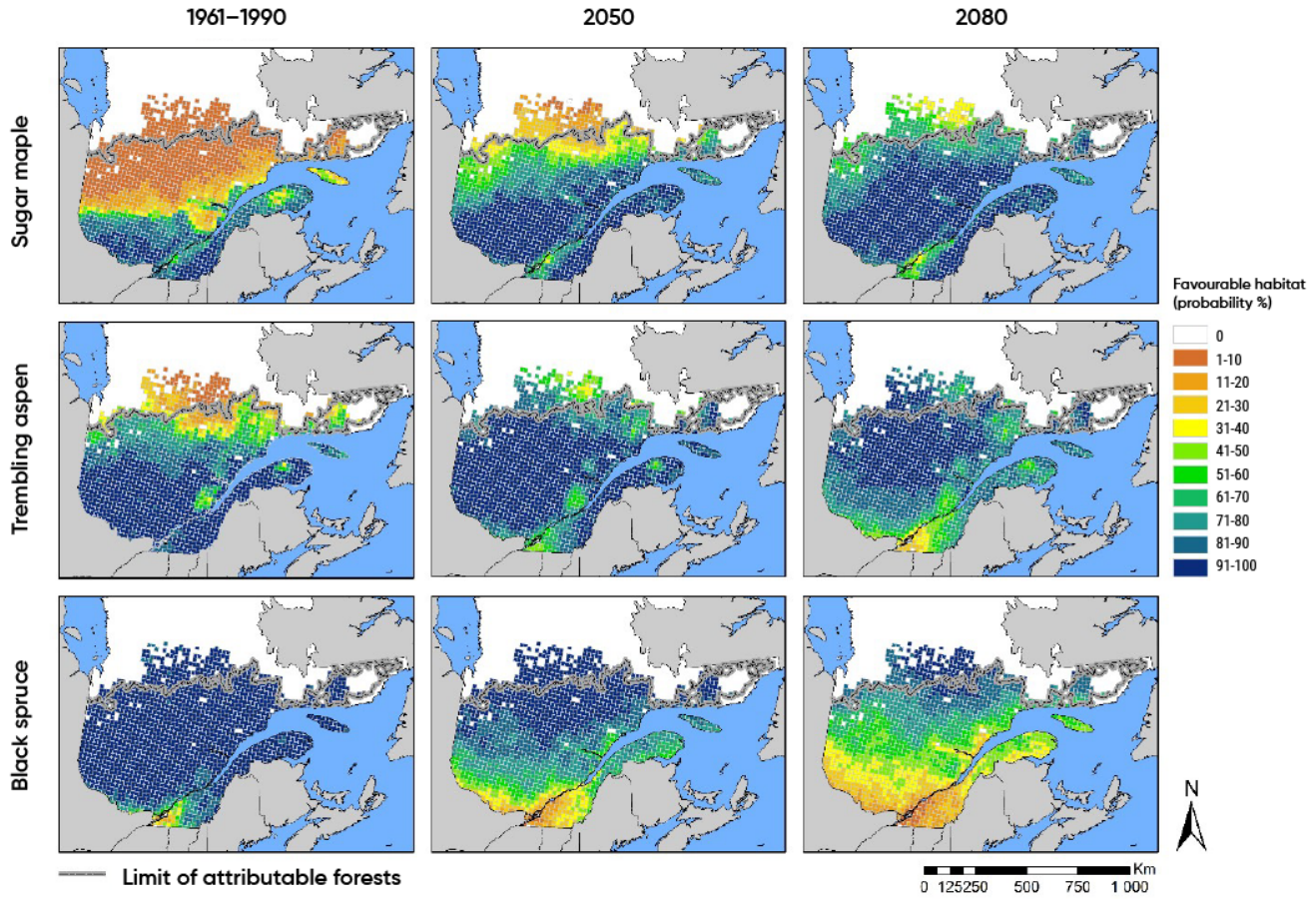


Figure 2.12: Probability of suitable habitats for sugar maple, trembling aspen and black spruce in 2050 and 2080 relative to 1961–1990. Source: Périé et al., 2009.

In southern Quebec, the fragmentation of natural habitats places additional stress on wildlife species that are already impacted by climate change. Their movements could be hindered by the presence of anthropogenic barriers (road networks, urban environments and agricultural areas) and natural barriers, such as the St. Lawrence River (Berteaux et al., 2014; Gonzalez et al., 2013). This landscape fragmentation, along with warmer temperatures, could also affect the occurrence and dispersal of invasive exotic species, as well as disease vectors such as Lyme disease and West Nile virus (Bouchard et al., 2017; Simon et al., 2014). For example, some studies have shown that the combined effects of natural habitat fragmentation and climate change can favour the spread of the white-footed mouse, which is the main host for the tick vector of Lyme disease. This mouse species has been shown to be a very effective transmission agent of this zoonotic disease in southern Quebec (Institut national de santé publique du Québec, 2020b; Briand et al., 2017; Millien, 2013).

Aquatic ecosystems are also likely to change. Various salmonids, particularly in northern Quebec, such as Arctic char, trout, lake trout and salmon, may be affected by a decline in their optimal thermal habitats and

may temporarily disappear from some shallow lakes during the summer due to rising water temperatures. This could increase the risk of mortality in these populations (Bélanger et al., 2017, 2013a).

2.7.3 Alteration of species life cycles

Climate change will also increase phenological mismatches by disrupting species life cycles (Zimova et al., 2018; Bellard et al., 2012). For example, depending on day length, the colour of the snowshoe hare coat changes from brown to white in winter (Zimova et al., 2018). This camouflage strategy may be ineffective with the late arrival of snow, causing snowshoe hares to be spotted more easily and thus making them more vulnerable to predation (*see* Figure 2.13; Zimova et al., 2018; 2016; Radio-Canada 2015b). Since hares are the primary prey of many predators in northern Quebec, variations in hare abundance could change the dynamics of predator-prey relationships in the ecosystem (Berteaux et al., 2018 c; Radio-Canada, 2015b).

Climate change also has a similar impacts in aquatic environments. For example, rising surface water temperatures are causing an earlier spring bloom in some plankton species (Shackell and Loder, 2012; Visser and Both, 2005). Because of this earlier timing, some deep-dwelling fish or crustacean species, such as northern shrimp, may not be at the right life stage to feed on them, resulting in significant mortalities (Bourduas Crouhen et al., 2017; Durant et al., 2007).

Figure 2.13: Camouflage mismatch in snowshoe hares due to late onset of winter. Source: © Nicolas Bradette.

2.7.4 Emergence and spread of invasive species

Rising temperatures and extended growing seasons favour the emergence and spread of many invasive species. A number of them are exotic species that have dispersed from more southerly regions or have been introduced through anthropogenic activities (e.g., transportation of goods), and have become established in both terrestrial and aquatic ecosystems. They are called invasive because of how quickly they colonize the territory and because they compete with native plant species that are adversely affected by climate change (de Blois et al., 2013).

In Quebec, climate change will exacerbate the spread of a number of invasive species, such as hemlock woolly adelgid (HWA) (McAvoy et al., 2017), Japanese knotweed, common reed and European common reed (de Blois et al., 2013; Tougas-Tellier et al., 2013), as well as some aquatic species that pose a threat to the waters of the Great Lakes drainage basin (Roy et al., 2018; Melles et al., 2015). For example, the northern limit of Japanese knotweed reproduction in North America is now located in the Québec City area, 500 km farther north than the former known limit on the continent, which was in Boston, Massachusetts, in the late 20th century (de Blois et al., 2013).

Some invasive species that thrive in Quebec due to climate change pose a threat to public health. This is particularly true of giant hogweed (de Blois et al., 2013) and ragweed (*Ambrosia*). The latter, which causes allergy problems in many people, may undergo range expansion and an increase in the duration of its pollen season due to higher temperatures (Larrivée et al., 2015; Lavoie et al., 2007).

2.7.5 Deterioration of ecosystems and ecological services

Ecosystems provide many services upon which humans depend. These include provisioning services (food, water, heat, fibre, timber, etc.), regulating functions (oxygen production, water and air purification, climate regulation, pollination, etc.), and sociocultural benefits, such as enhanced well-being related to nature, recreational and artistic activities, spirituality, etc. (*see* Ecosystem Services chapter; Díaz et al., 2018; Value of Nature to Canadians Study Taskforce, 2017; Siron, 2014).

Climate change impacts the functioning of ecosystems and, by extension, it has impacts on the ecological services they provide. Some of these services are particularly important for climate change adaptation (*see* Ecosystem Services chapter). This is the case for wetlands, which cover approximately 10% of Quebec's surface area (He et al., 2017; Pellerin and Poulin, 2013). Climate change and the associated hydrological impacts (*see* Section 2.6) could lead to the degradation of some ecological services provided by wetlands (Fournier et al., 2013) since these ecosystems act as a buffer for the water system by regulating river flows; maintain surface and groundwater quality by filtering sediments; protect shorelines from erosion; and provide quality habitat for biodiversity (Ouranos, 2017b). Protecting wetlands and their ecological functions is therefore critical for adaptation to climate change (Siron, 2014).

Climate change will also have impacts on aquatic environments (*see* Section 2.8.3). Expected impacts include thermal stratification of the water column, a decrease in the dissolved oxygen concentration, and an increased in the carbon dioxide concentration in the water, leading to acidification of lakes and watercourses

(Bourduas Crouhen et al., 2017; Shackell et al., 2013). These changes will make the habitat of many fish species unsuitable for their survival, and cause fish stocks to migrate (Shackell et al., 2013). For example, at Lac St. Pierre, a Ramsar site and UNESCO Biosphere Reserve, ecological services, such as fishing, recreation, tourism, and landscape quality are at risk. This situation has impacted the number and duration of visits to the site with significant consequences for the local economy (He et al., 2016).

2.7.6 Adaptation measures

To limit the contraction of species' ranges, particularly in densely populated areas, it is important to ensure connectivity between ecosystems (Mitchell et al., 2015; 2014; Gonzalez et al., 2013). With regard to habitat fragmentation, several decision support and land use planning tools can be used which consider ecological services, their economic value and how they will be modified by climate change (Fournier et al., 2013; Gonzalez et al., 2013) These include the Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands (Environment and Climate Change Canada and Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018) and the Atlas interactif sur les changements climatiques et habitats des arbres [Interactive atlas on climate change and tree habitats] prepared by the Ministère des Forêts, de la Faune et des Parcs (Périé et al., 2017). Several non-governmental organizations are also developing connectivity strategies and initiatives such as ecological corridors (Monticone, 2017) in order to address urban sprawl and habitat loss. This is the case for the ILEAU greening campaign, which is aimed at connecting the natural environments of East End Montréal (ILEAU, n.d.). The Ecological Connectivity web platform identifies projects aimed at maintaining or restoring terrestrial and aquatic ecological connectivity in Quebec, eastern Canada and New England (Ecological Connectivity, n.d.). The Nature Conservancy of Canada also acquires land to establish reserves for the protection of ecosystems and to ensure connectivity between them.

Wetland conservation also contributes to ecosystem connectivity and resilience (Ouranos, 2017b; Pellerin and Poulin, 2013). This type of conservation is governed by the recent *Act respecting the conservation of wetlands and bodies of water* (Ministère de l'Environnement et de la Lutte contre les changements climatiques du Québec, 2021b). Under this Act, RCMs are required to prepare regional plans for wetlands and water bodies. As a result, municipalities are addressing the protection of such water resources in their land use planning (Woods et al., 2019). The so-called "room for the river" management approach is also used in conservation and focuses on preserving a river's natural evolutionary processes and its response to hydroclimate changes (Ouranos, 2017b; Biron et al., 2013).

To address the expansion of invasive alien species, the Quebec government has established Sentinelle, a web-based identification tool enabling citizens to report the presence of such species (Conseil québécois des espèces exotiques envahissantes, 2014). A methodology has also been developed to assess the risks posed by invasive plants as a result of climate change (de Blois et al., 2013; Tougas-Tellier et al., 2013). Good practices exist to prevent the spread of invasive alien species between areas. For example, it is recommended to avoid leaving bare ground during roadside maintenance as it encourages the growth of invasive species (Tougas-Tellier et al., 2013). Planting fast-growing native species with some degree of functional diversity can also counter the spread of invasive species (Byun et al., 2018). Municipalities can use a methodology to increase the diversity of their urban forest so that it is more resilient to climate change stresses (Paquette and Messier, 2016). The Ministère de la Santé et des Services sociaux has also developed a strategy to

integrate allergenic pollen control measures into the routine grounds maintenance practices of government departments and agencies as well as Quebec municipalities and boroughs (Demers, 2015).

Biodiversity monitoring is also important because it supports decision making and adaptation based on the evolution of ecosystems in Quebec. Several monitoring tools are available online, such as the QuéBio field data directory and Quebec's natural heritage data centre, the Centre de données sur le patrimoine nature du Québec (Data on Quebec's biodiversity, 2021; Gouvernement du Québec, 2005). There is also an ecological monitoring program for national wildlife areas in Quebec (Canadian Wildlife Service, 2017). In addition, the BdQc program to monitor biodiversity in Quebec in relation to climate change is currently being set up to assess the status of and changes in ecosystems, communities and populations over time (Coléo documentation, n.d.). This monitoring program is based on relevant scientific knowledge, including expert opinions, data, indicators and modelling, and will ultimately allow the Quebec government to integrate biodiversity into adaptation decision making more effectively (Peres-Neto et al., 2013).

2.8 The agricultural and fisheries sectors will experience gains and losses

In Quebec, the agricultural, fisheries and aquaculture sectors could experience gains and losses in productivity, the emergence of new crop pests, and the northward migration of fish stocks due to climate change. Stakeholders in these sectors have initiated adaptation efforts by developing and using decision support tools that consider climate change in their practices.

With regard to the agriculture sector in Quebec, new climatic conditions could favour the growth of certain crops. However, the anticipated gains may be constrained by more frequent extreme weather events, increasing pests, and potential water stress. Livestock could also be affected by heat waves and, indirectly, by a decrease in the productivity of some forage crops. For fisheries and aquaculture, certain physical water-related variables (e.g., temperature) are also expected to change, resulting in loss of fish habitat and the emergence of, or increase in, the number of invasive alien species and pathogens. Therefore, producers in these different sectors are beginning to modify their practices, switch to other species and varieties, adjust the number of harvests per season, and, exploit different growing regions where crop potential changes. They are increasingly using decision support tools such as a regional agroclimatic atlas or fish stock monitoring to integrate climate change adaptation into their practices.

2.8.1 Introduction

Due to Quebec's northern climate, agriculture has developed around animal production, including dairy production, but has also diversified into grain, oilseed, fruits and vegetables, and maple syrup production (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2018; Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2014). With 28,000 farms, this sector generated nearly 60,000 jobs and $8.8 billion in revenue in 2017 (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2018).

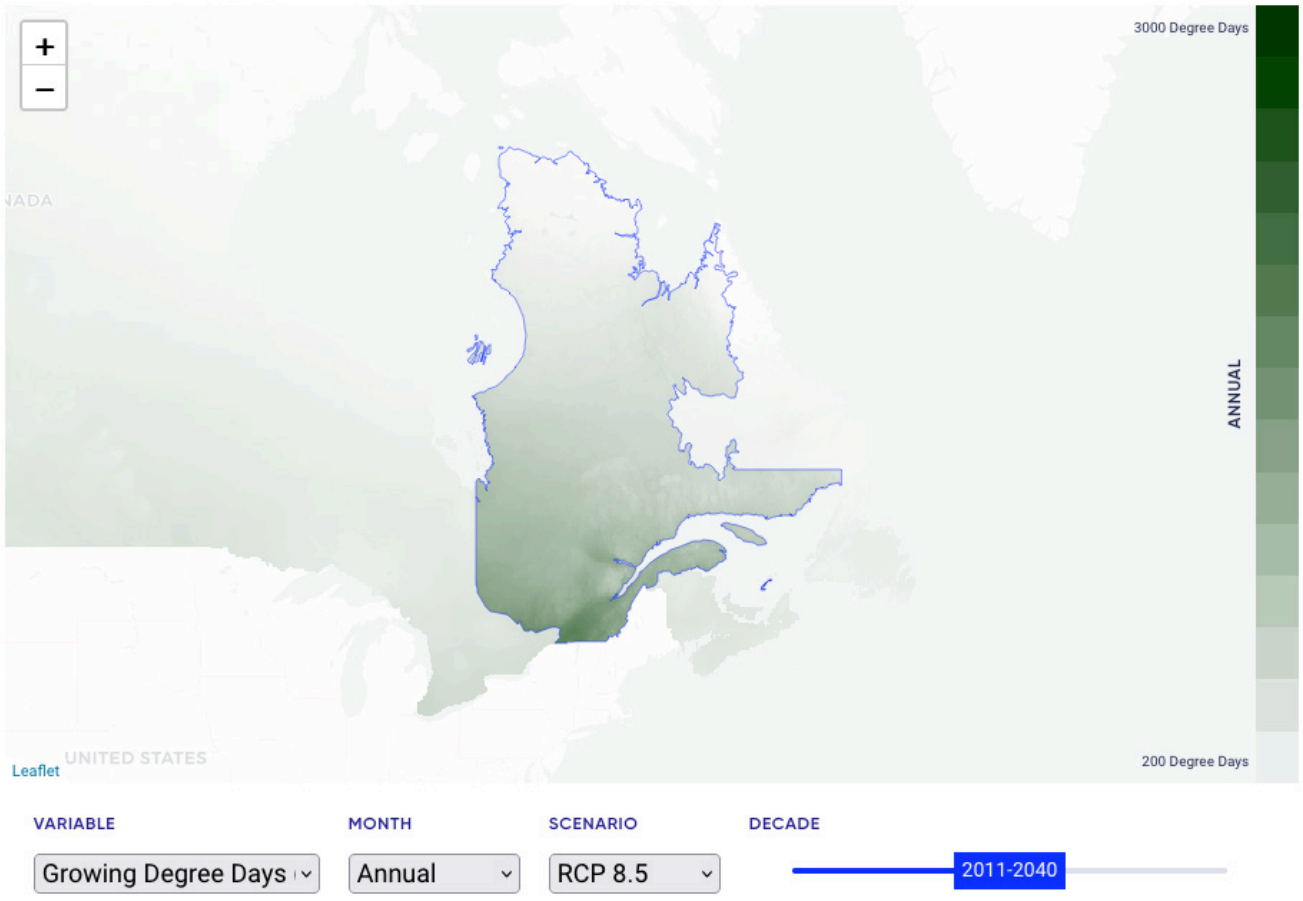
Commercial fisheries tend to target lobster, shrimp, crab and groundfish, and are critical to maritime regions (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2018). The fisheries sector accounted for more than 8,000 jobs in 2017 in the maritime regions of Quebec, and landings and shipments with a value exceeding $1 billion (Gouvernement du Québec, 2018b).

Rising temperatures, increased frequency of natural disturbances (e.g., droughts and insect outbreaks), longer growing seasons and frost-free seasons, in addition to changes in some physical and chemical water variables, are climate-related changes that will impact these sectors (Li et al., 2018; Ouranos, 2015b).

2.8.2 Agriculture

2.8.2.1 Opportunities and risks related to crop growth

In Quebec, climate change will have varying impacts on the potential yields of forage and vegetable crops, as well as on livestock. The production of several crops, including soybeans (Gendron St-Marseille et al., 2019; Jing et al., 2017), corn (Bryant et al., 2016), and some forage species (Thivierge et al., 2017), such as timothy and timothy/alfalfa mixtures (Tremblay et al., 2018; Thivierge et al., 2016; Bertrand et al., 2014; Jing et al., 2014), could benefit from a longer growing season. These yield gains generally depend on adapting cultivation practices such as changing the timing and number of harvests, as well as using cultivars that are better adapted to future climate conditions. Conversely, crops that are better adapted to cool regions, such as canola (Qian et al., 2018), barley and wheat, may be adversely affected by warmer growing conditions (*see* Figure 2.2 and the portal *Portraits climatiques d'Ouranos* [Ouranos, 2018c] for additional figures; Ouranos, 2015b).



Snapshot of interactive Figure 2.2: Trends in growing degree days (base value of 5 °C).

The spatial distribution of some crops could be extended if soils and topography are suitable. Grain corn and soybean crops could expand further north, as could the commercial apple production area, which is currently limited to the southern regions of Quebec (Gendron St-Marseille et al., 2019; Bélanger, 2016; Ouranos, 2015b). These changes could improve Quebec's competitive position for these agricultural products (Tamini et al., 2015, 2014; Rochette et al., 2004). By 2050, viticulture could also expand to regions with new wine-growing climate potential, such as the St. Lawrence Valley and the southern part of the Outaouais region (*see* Figure 2.14; Roy et al., 2017b).

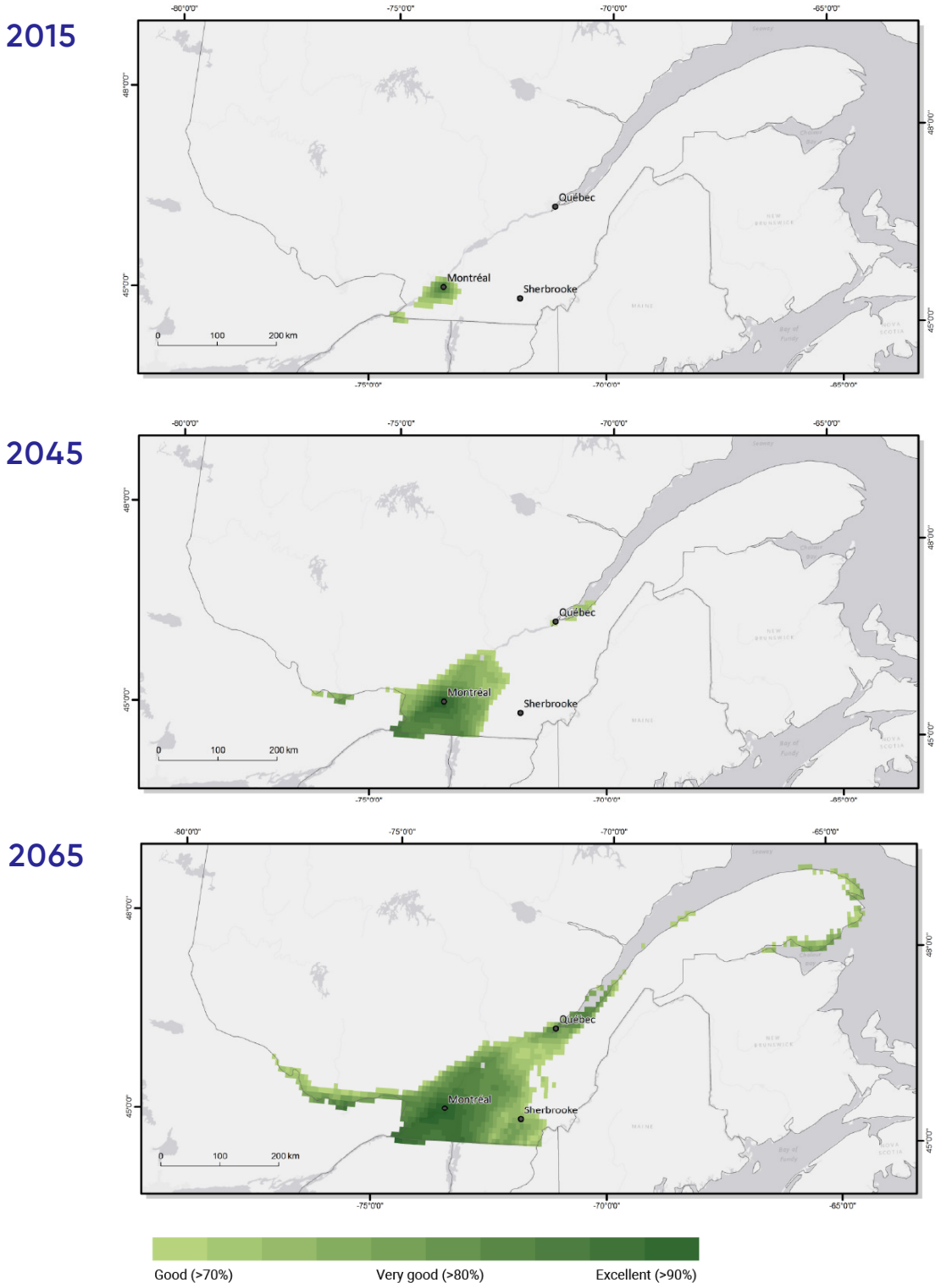


Figure 2.14: Trends in the viticultural potential of the St. Lawrence Valley according to a combination of RCP 4.5 and 8.5 scenarios. Source: Roy et al., 2017b.

2.8.2.2 Winterkill risks

Conversely, climate change could exacerbate several risks that, if poorly managed, could undermine the benefits noted above. For example, winterkill of perennial crops (e.g., alfalfa, orchardgrass), which are used in cattle feed among other things, could be exacerbated by warmer autumns, as well as more frequent winter thaws and rain events (Belanger, 2016). These conditions are unfavourable for cold hardening of these crops and can cause physical damage. The lack of snow cover will also expose them to temperatures that are too cold for their survival (Tremblay et al., 2018; Bélanger, 2016; Ouranos 2015c; Bélanger et al., 2002).

2.8.2.3 Crop pests

Climatic variations could also promote the proliferation, dispersal and introduction of certain diseases, weeds and invasive alien species (Gagnon et al., 2019; Saguez 2017; Forest 2016; Brodeur et al., 2013; Gagnon et al., 2013; Gagnon et al., 2011) For example, the soybean cyst nematode, which was first detected in Quebec in 2013, may expand its range by 2050 due to warming temperatures (Gendron St-Marseille et al., 2019). Increasing pest pressure is likely to influence pesticide use, leading to impacts on the quality of the environment and human health (Gagnon et al., 2019, 2015; Boileau, 2015).

2.8.2.4 Hazards and yield

During the summers of 2017 and 2018 in the Lower St. Lawrence region, potato (Ouellet, 2017) and hay (Gamache-Fortin, 2018) yields were below average due to significant periods of drought. With climate change, such water deficits could occur more frequently and affect nutritional quality and harvest quantity (Forest, 2016).

Extreme heat events, even very short ones (Pearce et al., 2014), can be harmful to livestock such as cattle, pigs, and poultry, potentially affecting their weight gain, milk or egg production, reproduction, and well-being (Fournel et al., 2017; Hristov et al., 2017; Sejian et al., 2015; Charbonneau et al., 2013).

Meanwhile, intense rainfall events and excess water will increase the already significant risks of crop damage, surface runoff and soil erosion, promoting the transfer of nutrients and pesticides to surface waters (*see* Section 2.6.3; see Water Resources chapter; Forest, 2016; Gagnon et al., 2015; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2015). These rainfall events may also impact open-air manure storage facilities and spreading schedules, which in some cases may necessitate adjustments to the related design and management criteria (Godbout et al., 2013).

2.8.2.5 Adaptation measures in agricultural settings

Achieving the full growth potential of some crops in the context of climate change requires, among other things, adapting cultural practices (Bryant et al., 2016; Desjarlais and Da Silva, 2016; Morissette and Jégo, 2016; Lease et al., 2009). This may include changing sowing and harvesting dates, increasing the number of

harvests for forage crops, developing regions with new crop potential, and using cultivars and hybrids that are better suited to future climate conditions.

For assistance with pest control, farmers can consult the Quebec plant protection warning network as well as models that help predict pest development (Agriréseau, n.d.; Plouffe et al., 2012) such as the one developed by the Computer Centre for Agricultural Pest Forecasting (CIPRA), to determine the best type of phytosanitary intervention (Gagnon et al., 2013). The Stratégie phytosanitaire québécoise en agriculture (Quebec's agricultural pest management strategy) promotes the principles of integrated pest management (Gouvernement du Québec, 2017b; Gouvernement du Québec and Union des producteurs agricoles, 2011), which suggest that alternatives to pesticides, such as the use of more resistant cultivars, should also be considered (Gouvernement du Québec and Union des producteurs agricoles du Québec, 2011).

Some soil conservation practices can reduce the negative impacts of heavy rainfall (Ouranos, 2015b); they include reduced tillage, incorporating riparian buffers, promoting cover crops, or adopting integrated fertilizer management (Kaye and Quemada, 2017; Ouranos, 2015b). Some of these practices are encouraged by the Quebec government's Prime-Vert incentive program (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, 2021).

Heat stress in livestock can be minimized through proper nutrition, a reduction in animal density per building, and better temperature control in buildings (Fournel et al., 2017; Sejian et al., 2015).

Farmers and other stakeholders in Quebec's biofood sector have access to several adaptation support tools, including the Agrométéo Québec weather forecasting site and Quebec's Atlas agroclimatique (agroclimate atlas), which provide information on the current and future climate change impacts for southern Quebec (*see* Box 2.3; Agrométéo Québec, 2019). In fact, some users of the agroclimate atlas report using it to "select crops or cultivars best suited to climatic conditions," "support teaching or research," "consider purchasing of farmland," "plan planting or seeding," and "educate colleagues or clients about climate change and its impacts" (Bachand et al., 2019).

Farmers and market gardeners can also manage certain risks by participating in the crop insurance programs of the Financière agricole du Québec, which provide compensation for losses associated with weather conditions (Gouvernement du Québec, 2016a).

At the regional scale, agricultural zone development plans [Plans de développement de la zone agricole (PDZA)] constitute a tool that can be used when considering the potential impacts of climate change and during other planning processes related to farmland in Quebec's RCMs (ÉcoRessources, 2018; Bryant, 2017a, b).

Diversification of forms of agriculture (personal gardens, urban agriculture) makes society more resilient to climate change and can generate a number of positive co-benefits for health, food security and social cohesion, as well as a sense of accomplishment (Duchemin et al., 2021). While it is estimated that about 40% of Montréal residents are involved in urban agriculture, either in individual, collective or community gardens (City of Montréal, 2013), the Montreal Urban Ecology Centre, in collaboration with Ouranos, provides an overview of this type of agriculture in the Montréal Metropolitan Community, in addition to informing Quebec social stakeholders about the related benefits for climate change adaptation (Duchemin et al., 2021).

Box 2.3: The Agriclimate Project

Agriclimate is a project initiated by Quebec agricultural producers to improve understanding of the impacts of climate change on agriculture and to determine the best ways to prepare for these impacts. Regional working groups, made up of farmers and other stakeholders, are tasked with identifying issues, threats and opportunities, as well as adaptation measures to be implemented in their respective administrative regions. Nine regions have participated in this program. The Agriclimate website offers a host of resources such as webinars and documentation on the production of livestock, maple syrup, forage crops, fruits and vegetables, and field crops (Agrométéo Québec, 2019).

2.8.3 Fisheries and aquaculture

2.8.3.1 Changing conditions in the fisheries and aquaculture sector

Climate change is affecting both the marine and freshwater components of the fisheries and aquaculture industry. The higher air temperatures are affecting the surface water temperature (Long et al., 2016; Hebert, 2013), a situation that affects water quantity and quality and poses challenges for fish harvesting and farming (Bourduas Crouhen et al., 2017; Long et al., 2016; Benoit et al., 2012).

Climate change could cause range contraction or expansion for many species, thereby modifying the areas that are fished as well as yields (Cheung et al., 2013; Shackell et al., 2013). There is a chance that the range of the American lobster will expand in the medium term (Benoit et al., 2012). However, the projected water temperatures for 2060–2070 will be too warm for larval development in the southern Gulf of St. Lawrence. This will confine lobsters to deeper waters and thus to areas where lobsters are generally less abundant (Bourduas Crouhen et al., 2017; Benoît et al., 2012). This could have impacts on the lobster fishery, one of the most commercially valuable fisheries in Quebec with a landed value of over $70 million in 2015 (Bourduas Crouhen et al., 2017).

Rising water temperatures could also alter predator-prey relationships of harvested species by causing phenological shifts between their life cycle stages (Savard et al., 2016; Shackell et al., 2013), but also by promoting the emergence of invasive exotic species and pathogens (Shackell et al., 2013). In fact, since the natural barrier created by cold water is less effective in a changing climate, there may be an increase in pathogenic organisms and diseases in wild and farmed fish populations (Karvonen et al., 2010).

In sport fishing, an important segment of Quebec's tourism industry, the loss of thermal habitat for iconic fishing species, such as salmonids, could significantly affect sport fishing dates, areas, quotas, licenses, and fishing rights, particularly in the eastern and northern parts of the province (Daigle et al., 2015; Loder et al., 2015; Lapointe et al., 2013).

2.8.3.2 Adaptation measures for fisheries and fish farming

To ensure the economic development of fisheries and aquaculture, farming or harvesting of new species may become the norm due to changes in aquatic ecosystems (Brzeski, 2011). Adjusting quotas and fishing season opening dates are also measures that government authorities can use to limit the impacts on populations taking into account their development cycles (Ministère des Forêts, de la Faune et des Parcs, 2018b; Fisheries and Oceans Canada, 2018).

Species monitoring and habitat protection are best practices that are currently being implemented. One example is the risk assessment protocol developed for non-native marine aquatic species in order to prevent large-scale infestations by invasive alien species (Fisheries and Oceans Canada, 2015). Fisheries and Oceans Canada is working on a bill pertaining to sustainable fisheries with the aim of promoting habitat protection, improving management of economic development and promoting Indigenous rights (Fisheries and Oceans Canada, 2019).

2.9 The energy, forestry and mining sectors will be particularly impacted by climate change

Quebec's main natural resource sectors, namely energy, forestry and mining, will be particularly impacted by climate hazards. These hazards may impact operations, production, facilities and maintenance activities in these sectors. Producers are gradually adapting their decision-making processes and management methods to deal with climate change.

New climatic conditions could present both opportunities and risks for Quebec's natural resource sectors, which account for nearly 7% of the gross domestic product. Higher precipitation amounts in regions with large reservoirs will increase the potential for hydroelectric generation; however, not all facilities have been designed for an increase in holding capacity or productivity based on expected water volumes. Increases in boreal forest growth may be constrained by forest fires, more frequent extreme weather events and potential water stress. Management practices are beginning to change to make forests more resilient to climate change. Similarly, adaptations of management of retention structures and tailings facilities in the mining industry are beginning to be implemented.

2.9.1 Introduction

In Quebec, the main natural resource sectors, specifically energy, forestry and mining, together account for about 7% of the gross domestic product (GDP) (Statistics Canada, 2016c). Rising temperatures, an increase in the frequency of natural disturbances such as wildfires, droughts and insect outbreaks, as well as changes in water regimes (Li et al., 2018; Ouranos, 2015b) are hazards that will impact these sectors.

2.9.2 Energy

Energy consumption in Quebec is dominated by oil which accounts for 40%, followed closely by electricity at 36% (Whitmore and Pineau, 2020). In its most recent energy policy (2016–2030), the Ministère de l'Énergie du Québec has set a goal of reducing petroleum product consumption by 40% and increasing renewable energy use by 25% (Gouvernement du Québec, 2016b). In the coming years, the proportion of oil in Quebec's energy portfolio should therefore decrease (Whitmore and Pineau, 2020) in favour of renewable energies, which will be affected by climate change.

Hydroelectric plants generate about 95% of Quebec's electricity (see Figure 2.15) and are mostly operated by Hydro-Québec, a Crown corporation (Canada Energy Regulator, n.d.; Whitmore and Pineau, 2020). Hydro-Québec's operations account for 4% of Quebec's total GDP (Hydro-Québec, 2018). However, climate change will have impacts on this source of revenue and on energy demand, particularly due to changes in water regimes and temperature variations (Ouranos, 2015b).

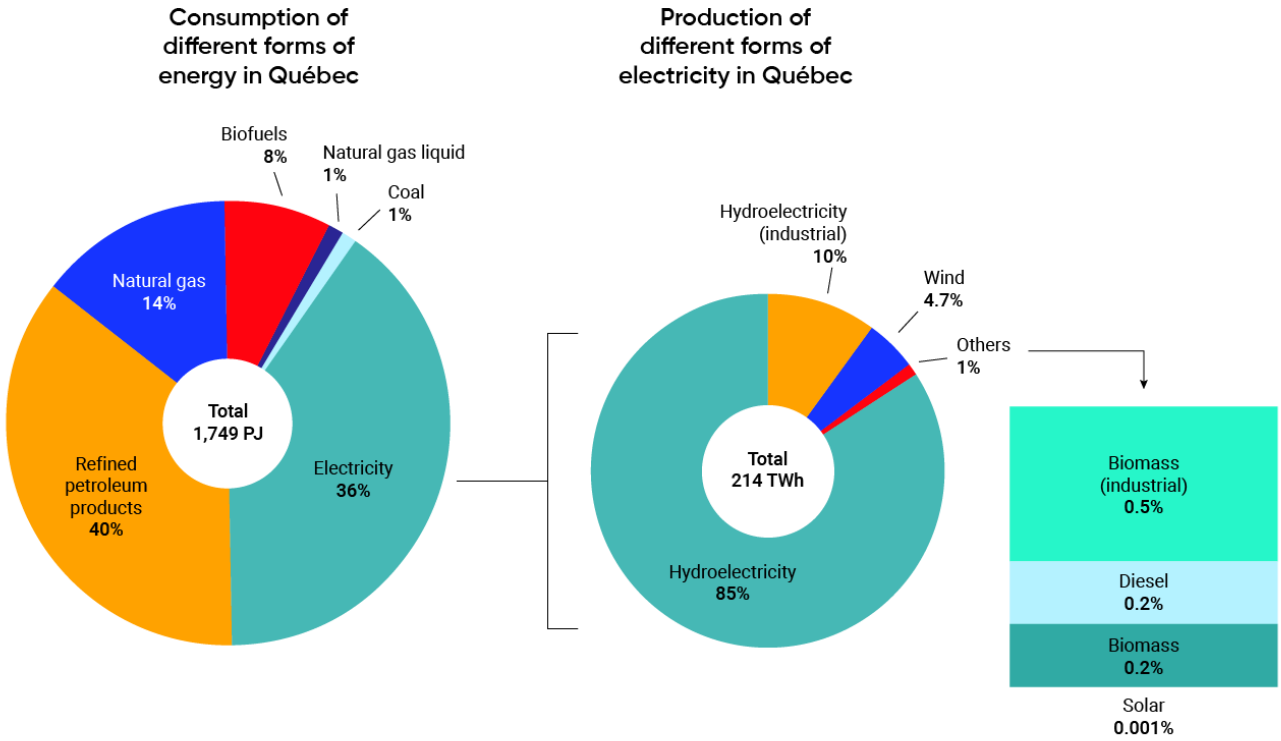


Figure 2.15: Total consumption by energy type in Quebec in 2017 (left) and electricity production by energy source in Quebec in 2018 (right). Source: Whitmore and Pineau, 2020.

2.9.2.1 Variations in hydroelectric generating capacity and risk of dam failure

As a result of climate change, winter and spring precipitation will tend to increase and be accompanied by more frequent winter thaws and extreme rainfall events (Ouranos, 2018c, 2015a; Tilmant et al., 2017; Sillmann et al., 2013; Monette et al., 2012). This will have a direct impact on the hydrological regimes of rivers, resulting in higher winter flows and earlier spring freshet across Quebec, with more pronounced changes in the north (Tilmant et al., 2017; Guay et al., 2015; Lachance-Cloutier et al., 2015; Ouranos, 2015b).

Some hydroelectric plants could thus see an increase in production (Guay et al., 2015), provided that an appropriate management plan is adopted (*see* Box 2.4; Fournier et al., 2020; Boucher and Leconte, 2013; Minville et al., 2010). However, the benefits associated with this water surplus may be limited if the increased flows occur at times when reservoirs are near their maximum storage capacity or, in the case of run-of-river plants, approaching their maximum productivity (Ouranos, 2015b; Boucher and Leconte, 2013).

Extreme rainfall events, on the other hand, could increase the frequency and extent of flooding and impact the magnitude of the probable maximum flood (PMF). The PMF is used as a design standard for large dams to prevent devastating overtopping, which can result in severe environmental, human and financial losses. For some Quebec reservoirs, an increase in the PMF in spring is projected for the 21st century; however, based on the expected increases, it has been determined that no changes are required to the structure of the dams to ensure their safety (Clavet-Gaumont et al., 2017; Ouranos, 2015a).

On the other hand, some systems, such as the Great Lakes system that supplies water to the Beauharnois generating station, could experience higher evaporation rates, which would result in lower water levels in the St. Lawrence River in late summer and early fall (*see* Section 2.5.4; Music et al., 2015). Hydroelectric power generation in these basins could decrease, causing significant economic losses (Desjarlais and Da Silva, 2016; Boucher and Leconte, 2013).

2.9.2.2 Changes in energy demand

Warmer temperatures will have an effect on seasonal energy demand. As early as 2030, lower heating needs in winter would only be partially offset by increased cooling needs in summer (Lafrance et al., 2016). However, several other factors, including the increasing electrification of transportation and the development of markets such as data centres, cryptocurrencies, and greenhouse cultivation, could impact energy demand in the future (Hydro-Québec, 2019).

2.9.2.3 Risks to electricity transmission and distribution infrastructure

With over 34,000 km of transmission lines and some 116,000 km of distribution lines (Canada Energy Regulator, n.d.), Hydro-Québec has the largest transmission system in North America (Whitmore and Pineau, 2018). The frequency and intensity of certain extreme weather events, which are expected to be altered by climate change, such as mixed precipitation in winter (rain, snow, freezing rain), extreme heat events in summer, wildfires and flooding, could significantly impact the structural integrity of the electricity transmission and distribution infrastructure and affect the efficiency of certain components, such as

transformers (Braun and Fournier, 2016; Ouranos, 2015c; Petit, 2015). These equipment issues can lead to service interruptions with associated social, health and economic consequences, as well as repair costs.

2.9.2.4 Adaptation measures

Adaptation measures are often introduced in the wake of devastating weather events. For example, after the 1996 Saguenay flood, a commission of inquiry concluded that the damage would have been less severe with better land use planning, different methods of infrastructure management (e.g., a decrease in the maximum operating level) and better emergency planning (Bureau d'audiences publiques sur l'environnement - Commission d'examen conjoint, 2003). In response to the commission's recommendations, Quebec adopted the *Dam Safety Act* and the *Dam Safety Regulation*, which provide for the development of a water management plan, an emergency response plan and monitoring activities for all dams in the province (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques - Expertise hydrique et barrages, 2018b). In addition, to prevent failure, dams must be designed to withstand large floods up to the maximum probable flood. Systems for monitoring and forecasting reservoir levels are used in this context (Leconte et al., 2017).

Changing emergency management measures and land use planning in the area downstream of dams (Ouranos, 2015a) are adaptation measures that require relatively modest investments. Regulatory adaptation measures may also be appropriate and can take advantage of additional water availability (Arsenault et al., 2013; Boucher and Leconte, 2013; Haguma, 2013). Incorporating climate data into demand forecasting is an approach that Hydro-Québec adopted to adapt to fluctuations in demand (Braun and Fournier, 2016).

Other possible adaptation measures include physical changes to systems, such as adding turbines or resizing equipment to take advantage of additional water inflows (Boucher and Leconte, 2013). However, these solutions are more expensive and technically more challenging and so they are seldom implemented. Furthermore, the return on investment for such measures carries risks due to the uncertainty related to hydrological projections (Clavet-Gaumont et al., 2017; Ouranos, 2015a; Boucher and Leconte, 2013; Haguma, 2013). These adaptation measures would ideally be implemented during the planning phase of dam construction or rehabilitation, as was the case at Hydro-Québec's Sainte-Marguerite-3 power station (Robert, 2018; Hydro-Québec, 1999). This structure was designed to allow for the addition of an extra turbine, which could be used for a potential diversion of the river providing the opportunity to produce more electricity.

Box 2.4: Value of hydroelectric assets and physical impacts of climate change

Owners and managers of hydroelectric facilities and other industry stakeholders make financial decisions based on the projected value of their assets. However, key components of the value of these assets, such as future revenues from electricity generation, may be affected by climate change. Ouranos, with support and funding from Natural Resources Canada, Manitoba Hydro, Ontario Power Generation, Innergex, Brookfield

Renewable and Hydro-Québec, has developed "A Guidebook to Integrate Climate Data in Energy Production for Value Modelling" (Fournier et al., 2020). This document and its four case studies provides guidance for hydroelectric industry stakeholders for implementing best practices for climate data integration.

In order to adapt the transmission system to climate change, Hydro-Québec has strengthened the design criteria for its potential Appalachian-Maine interconnection line (Hydro-Québec, 2020). Using the Ouranos climate profiles, some modifications were made to the usual design standards for this type of power line. It will be able to withstand higher temperatures as well as higher ice and wind loads. Since 2018, Hydro-Québec has also incorporated climate change as a business risk in its strategic plan and has established several committees to facilitate the coordination and integration of climate change adaptation across its different business units (Bonneau et al., 2019).

2.9.2.5 Other energy sources

Wind power is the second-largest source of electricity in Quebec, accounting for nearly 4.7% of electricity generation in 2018 (Whitmore and Pineau, 2020). Electricity generated by wind turbines could be affected by changes in wind speeds and distribution, temperature increases, lightning strikes, changes in vegetation types and permafrost thawing (Clavet-Gaumont and Huard, 2016). To date, very few studies have been conducted on future wind energy potential taking into account climate change, which is why Ouranos (consortium on regional climatology in Quebec) is conducting a research project on this issue with results expected in 2023 (Ouranos, 2017a).

Quebec's renewable energy portfolio is therefore expected to become more diversified over time. Solar energy could become a more important component, as could geothermal energy. That being said, the impacts of climate change on these energy sectors are still poorly understood (Ouranos, 2017a).

2.9.3 Forestry

The forestry sector is an important economic driver in Quebec. This industry generated total revenue of more than $10 billion in 2016, and it provided nearly 80,000 jobs (Gouvernement du Québec, 2017c). Forestry also contributes to the economies of 250 municipalities, many of which are solely dependent on this sector (Yamasaki et al., 2012; Gouvernement du Québec, 2006).

2.9.3.1 Impacts on forest growth

Expected climate change (Brown and Caldeira, 2017; Pedlar et al., 2015) could have positive impacts on tree growth in the short to medium term, especially in boreal forests where growth is constrained by temperature (Stinziano and Way, n.d.; Brown and Caldeira, 2017; D'Orangeville et al., 2016; Pedlar et al., 2015). The growing

season for trees has already increased by a few days to about two weeks depending on the region (Audet et al., 2012; Zhang et al., 2011), and trees are already showing some direct impacts, such as earlier bud burst (Raulier and Bernier, 2000). However, these growth gains could be limited by temperature increases that exceed the tolerance threshold of certain species such as black spruce and balsam fir (D'Orangeville et al., 2018). They could also be constrained by changes in the natural disturbance regime, such as forest fires, disease and insect outbreaks (Boucher et al., 2018; Gauthier et al., 2015).

2.9.3.2 Insect outbreaks

Quebec's forests are plagued by numerous insect pests such as the spruce budworm and the forest tent caterpillar. Climate change could have differing impacts on insect pests. In some cases, higher temperatures could cause an increase in their dispersal as well in the number of annual generations, in addition to affecting host tree defences (Pureswaran et al., 2018; Dukes et al., 2009; Levesque et al., 2002). In other cases, higher temperatures could lessen the severity of outbreaks by disrupting predator-prey relationships (Pureswaran et al., 2018). For example, a decrease in the duration and severity of spruce budworm outbreaks is expected to occur in southern Quebec (Boucher et al., 2018; Boulanger et al., 2016; Régnière et al., 2012). The range of the spruce budworm is expected to shift northward, leading to a decrease in the impacts of this pest on balsam fir stands. However, as this species moves northward, it could begin attacking black spruce in the future. The impacts will depend on the adjustment of the timing between larval hatch and black spruce bud break (De Grandpré et al., 2018).

Lastly, exotic pests from other countries, such as the gypsy moth (Régnière et al., 2009) and the hemlock woolly adelgid (McAvoy et al., 2017), may take advantage of the warmer winter temperatures to establish themselves in Quebec forests.

2.9.3.3 Droughts and forest fires

Owing to projected higher levels of precipitation in Quebec, droughts may cause less damage to forests in some regions of the province than elsewhere in Canada (*see* Sector Impacts and Adaptation chapter; Boucher et al., 2018; Gauthier et al., 2014). Nonetheless, given the anticipated increases in temperature and associated evapotranspiration, soil water content will decrease in the coming decades (Houle et al., 2012), which could impact tree growth and nutrition (Houle et al., 2016) and further increase the wildfire risk (Gauthier et al., 2014).

Changes in the fire regime could lead to fire becoming the greatest threat posed by climate change to Quebec's forests (Boucher et al., 2018; Lajoie et al., 2018). Depending on the region, the fire season could increase by 10 to 20 days by 2050, and fire frequency could be 1.5 times greater and the total land area burned could double (Natural Resources Canada, n.d.; Girardin and Terrier, 2015; Boulanger et al., 2014). The potential economic impacts of wildfire on the forestry sector in Quebec should be studied further.

2.9.3.4 Forest harvesting

Without the implementation of climate change adaptation measures, current harvest levels may be difficult to maintain (Boucher et al., 2018) and the quality of the harvested wood may decline (Gauthier et al., 2014). Between 5% and 21% of the current habitat of Quebec's main forest tree species (black spruce, balsam fir, white birch, yellow birch and sugar maple), which together account for 72% of the total volume of merchantable trees, could become unsuitable for their growth by the end of the 21st century (Périé and de Blois, 2016). The cost of forestry operations could also increase due to a decrease in the length of time that logging roads would be passable in winter, limiting access to forests during this period (Gauthier et al., 2014). The overall impacts could translate into job, property and infrastructure losses for the forestry and tourism sectors (Gauthier et al., 2014), with consequences for the province's economy as a whole (Boccanfuso et al., 2014; Tanekou Mangoua, 2013).

2.9.3.5 Adaptation measures

There are many potential adaptation measures for the forest sector (Gauthier et al., 2014), but some of them are difficult to implement. These measures aim to increase the resilience and/or resistance of forest stands to natural disturbances and environmental stresses. Examples include planting fast-growing tree species or varieties and adjusting the harvesting schedule (*see* Case Story 2.5; Park et al., 2014). The challenge will be to incorporate these measures and risk management practices into planning processes (Gauthier et al., 2014). In this regard, the Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP) has been conducting research for several years to increase knowledge of the vulnerability of forests and forestry operations to climate change (Ministère des Forêts, de la Faune et des Parcs, 2021; 2018c). In 2021, MFFP developed a draft strategy for adapting forest management to climate change, which completed public consultations in December 2021 (Ministère des Forêts, de la Faune et des Parcs, 2021). This strategy will help prioritize important issues and implement awareness measures for the forest sector.

Furthermore, the Chief Forester's office is integrating climate change impacts into the calculation of the allowable cut in Quebec, which represents a significant adaptation for this sector (Chief Forester, 2020).

Case Story 2.5: Impact of climate change on maple syrup production in Quebec

Maple syrup production is an important economic activity in northeastern North America, and particularly in Quebec, where more than 90% of Canadian production and about 70% of world production takes place (Producteurs et productrices acéricoles du Québec, 2020). Because the productivity of maple stands is largely dependent on climate (Duchesne and Houle, 2014; Duchesne et al., 2009), maple production is vulnerable to climate change. With spring arriving earlier, Quebec producers must begin tapping and sap harvesting operations earlier to avoid yield losses (Houle et al., 2015; Guilbert et al., 2014; Skinner et al., 2010). The southernmost regions of Quebec may experience a greater proportion of low production years, mainly

because of shorter seasons (Houle et al., 2015). In addition, the regions could be affected by an increase in insect outbreaks and drought events (Houle et al., 2012; Zarnovican, 2002; Gross, 1991), which would further affect maple health and decrease syrup yields. Several adaptation measures exist to address these potential challenges. According to a recent survey (Legault et al., 2019), Quebec maple syrup producers seem willing to implement such measures in the future, if they are not already doing so. Examples of adaptation measures include consulting weather forecasting sites, early tapping (in January, for example) and maintaining greater biodiversity within maple stands to improve their resilience to drought and pests (Legault et al., 2019).

2.9.4 Mining

The mining industry is experiencing a global boom due to the growing demand for advanced technologies and the rapid economic development occurring in some countries, such as China (Simard, 2019). Foreign companies in the extractive sector also see potential for investment in Quebec's Far North (Têtu and Lasserre, 2017). In Quebec, this sector generated over $8.6 billion (Mining Association of Canada, 2017) and employed nearly 16,000 people in 2016 (Institut de la Statistique du Québec, 2018b). It makes a significant contribution to the economy of several Quebec regions, with Abitibi-Témiscamingue, Nord-du-Québec, and Côte-Nord reaping the largest share of these benefits (Québec Mining Association, 2018). As of 2018, there were 24 active mines and about 30 mining projects in the province. Despite its economic benefits, the mining industry has significant social and environmental impacts (Simard, 2019).

2.9.4.1 Impacts on mine site operations and reclamation

The operation phase of a mine is short in duration and is particularly vulnerable to climate extremes, such as heavy rainfall (Bussière et al., 2017). Equally vulnerable to extremes, the reclamation phase is also subject to the cumulative impacts of long-term climate trends, such as increasing temperatures and thawing permafrost (*see* Sector Impacts and Adaptation chapter; Bussière et al., 2017). Therefore, the effectiveness of long-term reclamation methods and the longevity of tailings storage structures at the end of a mine's life represent the greatest vulnerabilities of the Quebec mining sector to climate change (Bussière et al., 2017). Indeed, mining generates "mountains" of tailings and "lakes" of mine wastewater (Mousseau, 2012). These tailings are often toxic and may contain arsenic, cyanide and, in some cases, radioactive elements. It is therefore critical to ensure that the materials in tailings impoundments cannot be carried off by runoff or percolate down into the water table (Simard, 2019).

Climate variability and extreme events are of the greatest concern to this sector. For example, increases in the frequency and intensity of extreme rainfall events could have significant consequences as not all spillways and overflow structures are designed with sufficient capacity to prevent the release of contaminated water into the environment (Bussière et al., 2017; Ouranos, 2015a). Thawing permafrost is also a concern for mine sites located in the northern part of the province that rely on the presence of permafrost to manage tailings.

This is the case for the Raglan Mine, which is located north of the 62nd parallel and will need to develop new storage strategies to ensure the stability of tailings management facilities, with or without permafrost, for at least the next 1,000 years (Blondin, 2020).

2.9.4.2 Adaptation measures

The industry has developed various frameworks to promote good practices. Under the *Mining Act*, the Government of Quebec requires that the development of reclamation plans consider the potential impacts of climate change on mining infrastructure since these structures will remain in place after mine closure (Gouvernement du Québec, 2017a). In accordance with the *Environment Quality Act*, any application for authorization of development projects must take into account the anticipated impacts of climate change and must include the implementation of adaptation measures to minimize risks (Québec, 2022). Since these legislative frameworks are recent and there are still few initiatives identified in Quebec, it remains important to monitor the effectiveness of these adaptation measures (Simard, 2019).

2.10 Tourism and financial sectors are feeling the impacts of climate change

Some industries, such as tourism and the insurance and financial service sectors are particularly sensitive to climate variations. In the last five years, a few companies, including some in the ski industry, have shown a proactive approach by implementing measures from a long-term planning perspective.

The climate changes that have already been observed, including more frequent extreme events, shorter winters and longer summers, have made many in the service sector aware of the direct impact of these changes on the sustainability of their activities. The tourism industry has adjusted its service offering and is adopting revenue diversification strategies that encompass all four seasons, in order to limit the risks it faces in a changing climate. Insurance companies are adapting their offering in keeping with the increase in extreme weather events. The financial services sector now favours portfolios made up of companies that disclose their climate change risks, allowing investors to make more informed decisions.

2.10.1 Introduction

The Quebec economy has become increasingly service-oriented. This service sector is composed of companies that provide commercial and administrative services, as well as all public and parapublic administration services. The tertiary sector accounted for over 80% of jobs in 2017 (Gouvernement du Québec, 2018c).

The observed and predicted effects of climate change will impact the entire business supply chain as well as public services such as health, social services and education. In the current economic context, short-term performance is prioritized and it is less common for tertiary sector businesses to devote resources to climate change adaptation (Eyzaguirre, 2016; National Round Table on the Environment and the Economy, 2012). However, a few service sectors in Quebec are beginning to consider the potential impacts of climate change over the short and long term in their business processes and decisions in order to ensure business continuity in the face of changing climatic conditions and the increase in the intensity and frequency of extreme weather events (Eyzaguirre, 2016).

2.10.2 Tourism industry

In Quebec, the tourism industry is a growing driver of the economy, with a 3% increase in tourist traffic recorded annually between 2014 and 2019 (Gouvernement du Québec, 2019a). Industry performance is strongly influenced by seasonality and weather extremes. Concerns differ from one tourism sector to another depending on the life expectancy of the infrastructure involved and peak visitor periods. For example, snow sports depend on the duration of snow cover and snow characteristics during peak periods (holiday season and spring break). The success of agri-tourism depends on water availability and sunshine, which are need to support quality local products and attract customers (Bleau et al., 2012). Water-based activities rely on safe water quality and sufficient water levels for various activities (Ferguson et al., 2018). In summary, climate change may present risks or opportunities depending on the region and tourism sector concerned (Paque et al., 2018; Ouranos, 2015b).

Variability in winter conditions will affect snow sports such as skiing and snowmobiling and, depending on the region, may cause a decrease in the number of visitors (Da Silva et al., 2019; Paque et al., 2018; Bleau et al., 2012). In addition, owing to milder winter conditions, some disease vectors, for example those that carry Lyme disease (Paque et al., 2018; Bleau et al., 2012), could survive the cold season and spread, potentially affecting outdoor activities.

Conversely, as the warm season is expected to be longer, some sectors could be presented with new business opportunities. This is the case for agri-tourism, cruises, golf, camping and other outdoor recreation sectors (Paque et al., 2018). For some regions, such as the Laurentians and the Eastern Townships, an increase in attendance at summer attractions and recreational activities is expected to occur (Bleau et al., 2012).

A 2017 survey of industry stakeholders revealed that many are not taking a proactive approach to addressing climate change impacts (Vachon and Germain, 2018; Chaire de tourisme Transat, 2017). Nonetheless, some are implementing voluntary measures such as diversifying activities at ski areas to generate revenue across the seasons (Sauvé, 2017; Paquin et al., 2016; Ouranos, 2015b; Egorova, 2014; Bleau et al., 2012; Scott et al., 2007). In addition, there is evidence of leadership emerging among some stakeholders on adaptation implementation (Leblond and Couture, 2017; Paquin et al., 2016; Bleau et al., 2015b; Blangy et al., 2011), such as a support initiative for the Laurentian region called *Living Lab Laurentides* (Living Lab Laurentides, 2018; Leblond and Couture, 2017). This initiative provides a framework for innovation and testing of concrete actions to combat climate change. In addition, recent research has produced specialized climate information for the tourism industry in the Québec and Charlevoix regions (Paque et al., 2018) and for some ski resorts

in the Eastern Townships (Da Silva et al., 2019) These new tools help decision makers identify vulnerabilities and opportunities for the tourism industry, so that it can better prioritize interventions and investments in the short and long term.

To help the tourism industry in Quebec gain a better understanding and appreciation of climate change issues, a sector-specific communications strategy is also developed at Ouranos, in conjunction with the Ministère du Tourisme (Chaire de tourisme Transat, 2017). It includes the development of a series of awareness-raising and risk assessment tools, along with activities that will help stakeholders consider climate risks and opportunities in their business models (Chaire de tourisme Transat, 2017).

2.10.3 Insurance sector

Property and casualty insurance companies are called on to play a larger role in risk coverage in Canada (Insurance Bureau of Canada, 2015), a situation that has exist especially since the major floods in Quebec (2011, 2017 and 2019) and Alberta (2013). The lake and river flood insurance market is in its infancy in Canada. As of June 2018, 16 insurers offered such coverage (Meckbach, 2018).

However, during extreme weather events, it is generally the different levels of government that provide compensation to disaster victims (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter; Ministère de la Sécurité publique du Québec, 2021; Insurance Bureau of Canada, 2015). The Government of Quebec provides financial assistance to municipalities, businesses, homeowners and tenants to cover the cost of the reconstruction or relocation of residences, etc. (Gouvernement du Québec, 2019c). This coverage model does not provide an incentive for citizens and developers to undertake development projects outside of risk areas. In contrast, private insurance could influence behaviours by sending a clearer signal concerning the costs of coverage (Insurance Bureau of Canada, 2015). The ability of insurers to predict losses and estimate risks arising from disasters is affected by climate change and thus requires improved risk calculations based on higher quality tools and data (Insurance Bureau of Canada, 2015).

A methodology has been developed in Quebec to analyze and quantify flood-related financial risks, taking into account the impacts of expected climate change on flood flows, to provide pricing of insurance products adapted to this type of risk (Boudreault et al., 2019). In addition, following the 2013 events in Calgary, insurers have taken steps to clarify the different types of covered and non-covered water damage (Insurance Bureau of Canada, 2015) and are considering changes to their coverage of flood risk across the country (Radio-Canada, 2017b; Thistlethwaite and Feltmate, 2013).

Furthermore, the development of other climate hazards could also influence the insurance industry, such as the increased frequency of forest fires, greater coastal erosion, or more extreme rainfall events. In Quebec, damage associated with extreme rainfall, such as pipes backing up, is one of the leading causes of home insurance claims, a risk that will increase due to climate change (Insurance Bureau of Canada and Groupement des assureurs automobiles, 2018; Ouranos, 2015c). The Insurance Bureau of Canada suggests steps individuals can take to reduce these risks, such as installing backwater valves or having aging roofs inspected (Insurance Bureau of Canada, 2017).

2.10.4 Finance sector

Canadian banks and financial services firms have been aware of the risks and opportunities presented by climate change for several years (National Round Table on the Environment and the Economy, 2012), as one of the key functions of financial markets is to estimate risk to support informed investment decisions (Task Force on Climate-Related Financial Disclosure, 2017). Across Canada, an expert panel on sustainable finance was established in 2018 to explore ways in which the financial sector can foster sustainable investments and direct funding to Canadian low-carbon initiatives (Government of Canada, 2019). The Bank of Canada is also conducting research in this area (Molico, 2019).

Mechanisms have also been established at the international level, such as the Task Force on Climate-related Financial Disclosures (TCFD). This is a working group that helps assess the physical, liability, and transition risks associated with climate change, and provides relevant financial information for all sectors, not just the financial sector (Task Force on Climate-related Financial Disclosures, 2018). The TCFD recommendations call for voluntary reporting in four areas: governance, strategy, risk management, and measures and objectives.

Some initiatives have also been undertaken in Quebec. The Caisse de dépôt et placement du Québec (CDPQ), the Bank of Montreal (BMO), and Desjardins are organizations and financial institutions that participated in a United Nations Environment Programme Finance Initiative (UNEP FI) pilot project to integrate the TCFD recommendations (UNEP FI, 2019). They have analyzed transition and physical risk scenarios associated with climate change to incorporate into their financial decisions for a more resilient portfolio (UNEP FI, 2019; Caisse de dépôt et placement du Québec, 2017).

Integrating climate change into the financial sector in turn encourages companies to adapt since it allows them to reduce their physical risks and become more attractive to investors (*see* Climate Disclosure, Litigation and Finance chapter; Task Force on Climate-Related Financial Disclosure, 2017). In 2019, an inventory on Quebec's eco-fiscal measures (incentives to implement measures that protect the environment) was carried out by the Chaire de recherche en fiscalité et en finances publiques [research chair in taxation and public finance] of the Université de Sherbrooke (Kerkhoff et al., 2019). Lastly, a research chair in macroeconomics and forecasting was established in January 2020 at the Université du Québec à Montréal, with a research focus on integrating the risks associated with climate change into macroeconomic analysis (Université du Québec à Montréal, 2020).

2.11 Moving forward

2.11.1 Research needs

Climate change and its impacts have been studied for several decades in Quebec. In spite of this, certain hazards and impacts are still uncertain or even unknown. Moreover, the analysis and implementation of

adaptation measures is still in its infancy. Different environments and sectors are at different stages of the adaptation cycle (*see* Figure 2.16). Thus, knowledge needs vary from one setting or sector to another. The following paragraphs present some of the gaps identified in the literature that are important for Quebec.

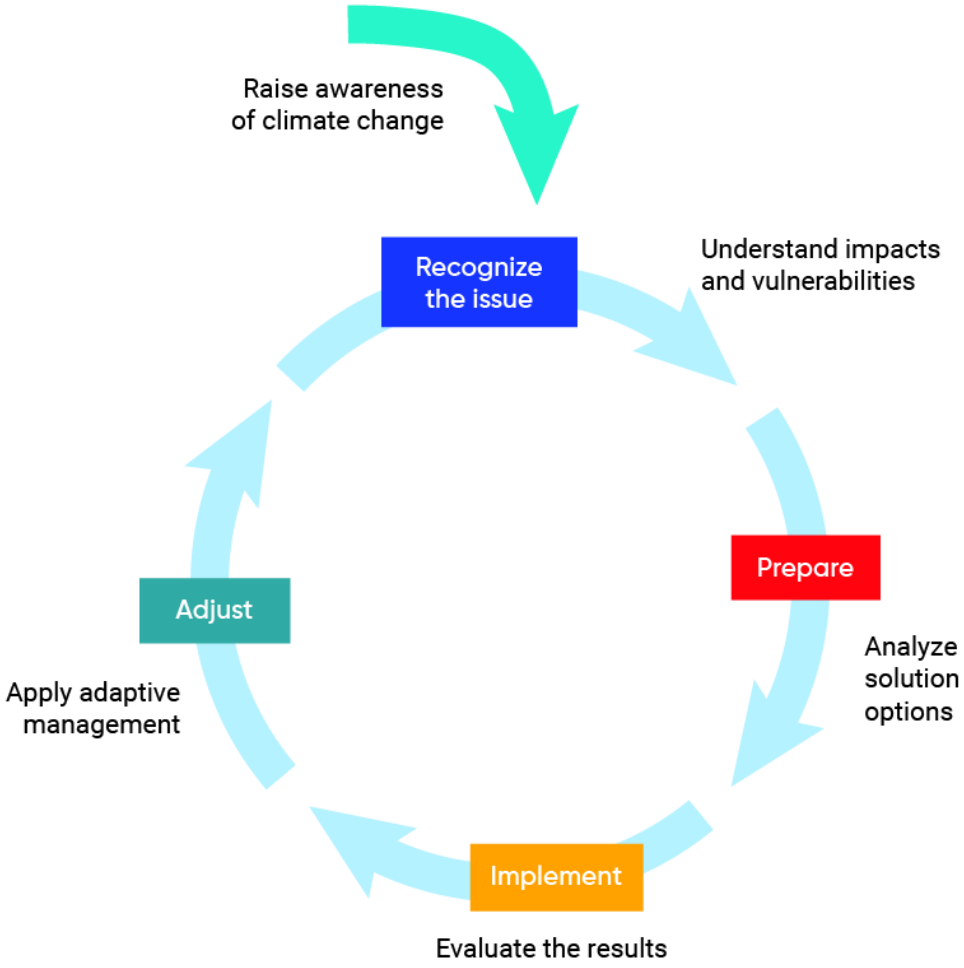


Figure 2.16: Climate change adaptation cycle.

2.11.1.1 Climate variables and hazards

The complexity of some climate variables and several hazards poses significant challenges for studying the climate system, both for observational and modelling purposes.

For example, wind and cloud forecasts are still very uncertain because these weather patterns are the result of a vast number of mechanisms at various scales. Nevertheless, winds are used to estimate Quebec's wind energy potential, and they affect sectors such as the built environment and agriculture (Ouranos, 2017a).

Clouds are also of great interest as they influence sunlight hours, but they still remain poorly represented in climate models (Roy et al., 2017; Boucher et al., 2013).

Knowledge is improving for some hazards, but much remains to be done before they can be predicted over time with a reasonable level of confidence. This is the case for the frequency and magnitude of storms that will hit the coastal regions of eastern Quebec in the coming decades (Ouranos, 2015a; Savard et al., 2008). This is also applicable to ice storms, which, following the 1998 crisis, are of concern to many sectors including those responsible for energy distribution (Hydro-Québec, 2017). This complex weather phenomenon is still not entirely understood and there are still many uncertainties about its future trends (Klima and Morgan, 2015).

2.11.1.2 Vulnerabilities and impacts

Considerable progress in recent years has further developed and consolidated the methods used to assess the physical, environmental, human, social, and economic impacts of climate change. This work has helped inform analyses of concrete adaptation measures (Ministère du Développement durable, de l'Environnement et des Parcs, 2012). Nevertheless, significant efforts are still needed in several areas, as noted below, to improve the identification and study of impacts and to understand the associated issues.

For example, extreme weather events could produce impacts that are disproportionately felt by the materially and socially disadvantaged. Research in the aftermath of Hurricane Katrina has shown that so-called disadvantaged groups (in this context, race is explicitly addressed as a source of marginalization) are often at greater risk of dealing with the long-term economic impacts of such disasters, which can affect the mental health of individuals (Masozera et al., 2007; Henkel et al., 2006). In fact, this work shows that social groups that have historically been discriminated against on racial grounds consistently receive less government assistance in response to their particular needs (Masozera et al., 2007; Henkel et al., 2006). It would also be worthwhile to investigate these aspects in Quebec.

Furthermore, from a climate justice perspective, it would also be relevant to better understand the impacts of climate change on people experiencing homelessness. For example, how heat waves, the spread of vector-borne diseases, and extreme weather events are likely to affect the living conditions (including mental health) of people experiencing homelessness, and how best to reduce the impacts on this population.

On another note, groundwater supplies over two million Quebecers with drinking water (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d). However, this water supply could be affected by climate change and undergo changes in quality and recharge (Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2017b). Furthermore, groundwater recharge modelling is still not very advanced in Quebec, although significant efforts have been made in this regard in recent years. Our knowledge remains fragmented (Gouvernement du Québec, 2019b; Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2017b; Bourgault et al., 2014; Levison et al., 2014) and the impacts of climate change are still poorly understood.

Several studies have suggested that the impacts of climate change may result in a shift of the salinity transition zone (STZ) in the St. Lawrence River (Villeneuve, 2002; Moulton and Cuthbert, 2000; Bourgault,

1999). Such a situation could compromise the supply of water intakes at the river for nearly 200,000 residents of the Québec Metropolitan Community (*see* Section 2.6; Communauté métropolitaine de Québec, 2017). In this context, community partners have developed a project that is currently underway to improve understanding of current and future sources of salinity in the STZ (Communauté métropolitaine de Québec and Ouranos, 2019). Although preliminary results do not allow for an accurate assessment of the probability and impact of a possible shift in the saline front on intake supply, it is clear that changes in salinity will occur in the medium to long term. Additional scientific monitoring and research on the STZ will be required. In the meantime, the researchers in this study recommend that water stakeholders apply the precautionary principle (Communauté métropolitaine de Québec and Ouranos, 2019).

Biodiversity monitoring is an important element in assessing ecosystem health. Currently, this monitoring across most of Quebec only considers the current climate, and only the northern Quebec region has been able to benefit from monitoring that takes into account future climate conditions (Berteaux et al., 2018d). However, to ensure better conservation of environments that provide ecological services, it will be important to monitor biodiversity under future climate conditions in all regions. On another note, studies on the genetic diversity of populations are still scarce and would also contribute to improved protection of ecological services (Gouvernement du Québec, 2019b).

As far as agricultural production is concerned, there is a fairly accurate picture of the main impacts of climate change. However, it is important to learn more about the costs of these impacts and possible adaptation measures (Ouranos, 2015b).

The mining sector is increasingly interested in the impacts of climate change on its facilities. Research on biophysical impacts needs to continue, particularly to assess the long-term impacts on retention structures after mining operations are completed. Certain technical construction and management criteria could be reviewed in light of potential impacts (Gouvernement du Québec, 2012).

2.11.1.3 Adaptation

Of the two broad categories of adaptation defined by the IPCC, Quebec generally focuses on those that are incremental in nature, i.e., measures that aim to preserve the essence, integrity, and values of our current societies as they are (Simonet, 2016; Ouranos, 2015c; IPCC, 2014c). The other category includes measures that are transformational in nature and require radical changes in the way we act (Simonet, 2016; Ouranos, 2015c; IPCC, 2014c).

For example, in agriculture, rather than just changing farming practices to maintain the same productivity, transformational adaptation would address the workings of the agri-food system (loss, waste, eating behaviour) (Simonet, 2016). Another example of transformational adaptation would be moving a population away from areas at risk of coastal erosion, rather than working to reduce their vulnerability in the at-risk locations. Although these transformations may face societal objections or reluctance, they may, in some cases, be necessary where incremental measures have reached their limits, or even generate co-benefits for other issues (population health, maintenance of biodiversity, robust economic structures, etc.). In Quebec, studies on climate change adaptation rarely propose measures of a transformational nature (Ouranos, 2015c).

Moreover, climate change research is primarily focused on climate modelling and biophysical impacts, with less focus on the social sciences and humanities, such as sociology, psychology, or political science (Bhatasara, 2015; IPCC, 2014e; Lever-Tracy, 2008). However, to advance the adaptation process throughout Quebec, a process that is eminently social, many issues will have to be addressed, particularly with regard to climate inequities, responsibility and risk transfer. There is also a need for transformative theories and strategies that help to better identify the roles of different societal actors (citizens, governments, businesses, insurers, etc.), depending on their setting or scale of action (Noblet and Brisson, 2017).

Furthermore, the impacts of climate change on the sense of well-being and overall health, as well as how they hinder or enhance the resilience of various social groups in Quebec, will be a key research topic to inform climate change adaptation efforts in the future.

At the same time, there is a strong lack of indicators of the capacity to adapt to different climate hazards in Quebec. It is important to study the vulnerability component, since it is precisely this vulnerability that government policies can address (Barrette et al., 2018). From this perspective, it will also be highly relevant to look at the means of financing, promoting, and implementing adaptation measures, as well as learning from the past two decades of public investment (Vérificateur général du Québec, 2019).

Lastly, ongoing organized and independent monitoring of adaptation measures, as well as the development of indicators for their performance and synergies with greenhouse gas mitigation measures, will go a long way toward creating or improving solutions to make adaptation measures more effective and relevant.

2.11.2 Emerging issues

Climate change is already having an impact on several socio-economic sectors. However, some consequences are still unknown. The main emerging issues, listed below, can be positive or negative.

2.11.2.1 Water availability and quality

In Quebec, floods have been widely studied, documented, and publicized because of the extensive damage they have caused. However, more severe and longer low water periods are also expected, and these could affect the availability and quality of drinking water in Quebec. Increased low water levels, particularly in the St. Lawrence River, could cause considerable damage given that the river is the source of drinking water for nearly one third of Quebec's population (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques - Expertise hydrique et barrages, 2018a; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d; Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2017b; Music et al., 2015). These changes may require adjustments in water use (by residents, agriculture, and industry), pump and plant piping modifications (Larrivée et al., 2016; Chan et al., 2015), and distribution system rehabilitation. The effect of climate change on the entire Great Lakes system will also need to be considered since the flows of the St. Lawrence are dependent on it (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d).

2.11.2.2 Commercial competitiveness

Certain agricultural sectors in Quebec could become more competitive than those in the United States due to changing climatic conditions there. For example, in Iowa and Illinois, corn growing could be adversely affected by 2050, thereby improving Quebec's competitive position as a grain corn producer (Tamini et al., 2014). Conversely, other economic activities dependent on natural resources that are strongly affected by climate change could put Quebec's trade position at a disadvantage.

In addition, the impacts of climate change on our international trading partners could limit current trade (imports and exports) and affect the price of goods and food (*see* International Dimensions chapter). For example, for foods that cannot be grown in Quebec, such as oranges, rice, and sugarcane, production losses due to changing climate conditions elsewhere in the world could increase food prices by 2050 and affect food security (Charlebois et al., 2018; IPCC, 2014d). This could exacerbate social inequalities, which would also increase the potential for social instability (Hendrix and Haggard, 2015). This, however, could represent an opportunity for local Quebec products to replace imported products at a lower cost, which would be both an adaptive and a mitigation measure.

2.11.2.3 Opening of the Northwest Passage

Due to the opening of the Northwest Passage (Fortier-Lacombe, 2010), combined with the lengthening of the ice-free season in northern Quebec, this region could now be exposed to increased shipping. New opportunities for the extraction and export of previously inaccessible mining, oil, and gas resources may emerge (Têtu and Lasserre, 2017; Fortier-Lacombe, 2010). Arctic governance and cooperation with Indigenous Peoples are critical aspects of ensuring that these opportunities do not exacerbate the negative environmental, social, and economic impacts of climate change on this already fragile region (*see* International Dimensions chapter; Arruda and Krutkowski, 2017; UNESCO, 2009).

2.11.2.4 Climate migration

Climate change is a factor that may cause increased migration flows: in 2017, 18.8 million people in 135 countries were displaced by extreme weather events (*see* International Dimensions chapter; International Organization for Migration – Insights from the Global Migration Data Portal, n.d.; International Organization for Migration, 2018). In sub-Saharan Africa, South Asia, and Latin America, declining crop yields, water stress, more severe droughts, sea-level rise, and more frequent storm surges will drive tens of millions of people to migrate by 2050 (Rigaud et al., 2018).

To date, global data on transboundary migration in connection with disasters is limited (International Organization for Migration - Insights from the Global Migration Data Portal, n.d.; International Organization for Migration, 2018). Quebec could become a host country for such immigrants, but for the moment, there is no specific category established by the various branches of the international legal framework for transboundary migration due to the impacts of climate change. This makes it difficult to recognize their rights and thus the consequent assistance that could be granted to them (Béchard, 2018; Pillais, 2017).

2.11.2.5 Changes in behaviour

In Quebec, to ensure the adaptation of the greatest number of people, behavioural changes at the individual, industrial, and institutional levels will be required (Valois et al., 2018; 2017a; 2016a; Bélanger et al., 2013b). For example, a growing need for collaboration among different actors (citizens, businesses, organizations, and levels of government) currently conflicts with the traditional approach of working in silos and can slow down the adaptation process (Noblet and Brisson, 2017). The technical-scientific approach to risk management still dominates and adaptation is not addressed in a cross-cutting manner (Noblet and Brisson, 2017). Yet, scientific research and empirical evidence indicate that to ensure resilience to climate hazards, integrated and cross-sectoral management is paramount (Cloutier, 2018; Participants of the CatIQ's Canadian Catastrophe Conference, 2017).

At the same time, the need for local and regional authorities to establish frameworks that promote better adaptation to climate change, such as adaptation plans and coordination mechanisms, is increasingly acknowledged, but these remain uncommon and only voluntary in Quebec (*see* Cities and Towns and Rural and Remote Communities chapters; Valois et al., 2017a). In municipal settings, certain skills and beliefs will thus need to be reinforced to improve adaptive practices (Valois et al., 2017b).

2.12 Conclusion

In general, the different economic sectors in Quebec are in the process of taking (or have already taken) a first step toward assessing their vulnerabilities to climate change. However, the implementation of adaptation measures is uneven among the various sectors and remains a major challenge that needs to be overcome in some settings.

Extreme climate hazards and the significant damage they cause have often stimulated urgent action by some actors who have begun the adaptation process. For example, the recent floods of 2017 and 2019 prompted authorities to invest in several measures, including significant efforts to map flood-prone areas under current and future climate conditions (Ministère des Affaires municipales et de l'Habitation du Québec, 2019). This will be used particularly for the implementation of a real-time forecasting system of areas that could be flooded over a period of a few days, as well as for development, prevention, and response plans in case of a disaster (Ministère de la Sécurité publique du Québec, 2018b; Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2018d; Ouranos, 2018a).

Coastal erosion and submergence, which have also caused considerable damage in eastern Quebec, have generated significant investments in action research. Adaptation initiatives at the local level are multiplying. In fact, a coastal resilience project is underway to assess the exposure of the entire coastal zone to these hazards, to target priority areas for intervention, and to implement appropriate adaptation measures (Laboratory of Dynamics and Integrated Coastal Zone Management, 2017).

Although few Quebec municipalities have developed adaptation plans (Valois et al., 2017b), many are implementing measures to deal with the impacts of climate change. For example, to deal with major heat waves, which in some cases have resulted in deaths, there are several greening initiatives in urban areas, as well as prevention or intervention measures for extreme heat (Centres intégrés universitaires de santé et de services sociaux du Centre-Sud-de-l'Île-de-Montréal, 2018; Direction régionale de santé publique CIUSSS du Centre-Sud-de-l'Île-de-Montréal, 2018; Ville de Montréal, 2017).

For generations, Indigenous Peoples have demonstrated their great resilience and agency when faced with change (Ford et al., 2015; Pearce et al., 2015; Ford et al., 2014; Ford et al., 2010; Peloquin and Berkes, 2009; Berkes et al., 2000). The magnitude of the expected changes may challenge their ability to adapt. Thus, several communities are taking concrete steps to integrate climate risks into their territorial planning and to improve their living conditions. In fact, the Indigenous communities of Odanak and Wôlinak are among the few Quebec municipalities and communities that have prepared a climate change adaptation plan (Grand Conseil de la Nation Waban-Aki, 2015b).

Agricultural producers are also on the front line of climate change impacts, which explains the use of numerous tools to observe changes that may affect production over the longer term (Agrométéo Québec, 2019). Training and awareness workshops have proven to be effective in helping farmers implement adaptive practices (Agriclimate, n.d.).

Other private sectors such as natural resource extraction and the tourism industry, whose activities are also highly dependent on climate, are more reactive than proactive when faced with climate hazards (Vachon and Germain, 2018; Transat Chair in Tourism, 2017). However, recent advances in knowledge on climate change impacts on these sectors, as well as significant engagement by stakeholders, are currently preparing these industries for the impacts they may experience (Da Silva et al., 2019; Paque et al., 2018; Leblond and Couture, 2017; Blangy et al., 2011).

Nevertheless, there are still several knowledge gaps, including social science and adaptation methods of a more transformative nature. Research must therefore continue to fill these gaps and support socio-economic sectors in assessing their risks, developing adaptation strategies, and implementing and monitoring them.

The goal of adaptation is to learn to live with climate change, which is inevitable. Adaptation efforts in the coming years will reduce the economic and human impacts of weather events, and even seize some opportunities that may arise (Ouranos, 2019). That being said, reducing greenhouse gas emissions remains a priority to avoid the worst-case scenarios of climate change, to which society would be unable to adapt.

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CHAPTER 3

Ontario

REGIONAL PERSPECTIVES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key Messages

Ontario's infrastructure is vulnerable to climate change (see section 3.2)

As a result of interdependencies between multiple infrastructure types, climate change and especially extreme climate events can have cascading economic and social impacts. Flooding in the highly populated southern subregion, and impacts on winter roads in the northern subregion of the province demonstrate the range of risks. Targeted approaches to better understand the threats, and reduce infrastructure vulnerability are being used across the province.

Nature-based approaches help address climate change impacts on biodiversity and ecosystem services (see section 3.3)

Climate warming has driven and will continue to drive changes to species and create new opportunities for invasive species. Impacts on biodiversity are magnified through the cumulative effects of climate change, habitat loss, urbanization, pollution and other threats. Actions to mainstream nature-based solutions, including the establishment of protected areas, such as Indigenous Protected and Conserved Areas, can help maintain ecosystem services and reduce climate change risks, as well as mitigate climate change.

Adaptive management is key for addressing impacts in the Great Lakes Basin (see section 3.4)

The combined effects of climate change, land-use changes and other stressors are negatively impacting the Great Lakes Basin. Despite mechanisms to address complex governance challenges, adaptation efforts across the Basin remain relatively fragmented. Many communities have embraced adaptive management practices to address impacts in light of uncertainties in future changes.

Adaptation improves forest health, carbon storage and biodiversity (see section 3.5)

Climate change impacts the composition, disturbance regimes, and timing of life cycle events in Ontario's forests and forested landscapes. Changes in drought, pests, and fire and wind regimes are of particular concern given the resulting cumulative impacts.

Climate change brings threats and opportunities to Ontario agriculture and food systems (see section 3.6)

Longer growing seasons and warmer average temperatures will benefit the agriculture sector in some parts of Ontario. However, projected reductions in summer rainfall along with more severe heatwaves, higher frequency of precipitation extremes, and increased risks from pests and diseases threaten farm operations, as well as supporting activities, such as food processing and distribution. Increased capacity and adaptation across the sector would permit the seizing of opportunities and management of risks posed by climate change.

Existing human health inequities will be worsened by climate change (see section 3.7)

Many non-climate factors, including income, housing quality and employment, play key roles in determining the vulnerability of communities and individuals to the health risks of climate change. Marginalized and low socio-economic populations will experience disproportionate health impacts and will have increasing difficulty in coping and adapting. Regional and local assessments of climate change vulnerability that include consideration of health equity provide a foundation for stronger and more widespread adaptation action.

Progress on adaptation remains limited in Ontario (see section 3.8)

Levels of climate change adaptation planning and implementation vary considerably across Ontario, with the primary focus still placed on the assessment of risk and vulnerability. Although there are examples of implementation, there is little evidence of adaptation being mainstreamed into decision making broadly. Systems for monitoring and evaluating adaptation action and effectiveness remain inadequate in most jurisdictions.

3.1 Introduction

Canada's climate is warming at a rate about twice that of the global average (Bush and Lemmen, 2019). Ontario's mean annual temperature increased by 1.3 °C between 1948 and 2016, with mean annual precipitation increasing by 9.7% over the same period (Bush and Lemmen, 2019). Climate model projections indicate that these changes will continue, highlighting that the risks currently presented by climate change will become even greater in the future (*see* Figure 3.1).

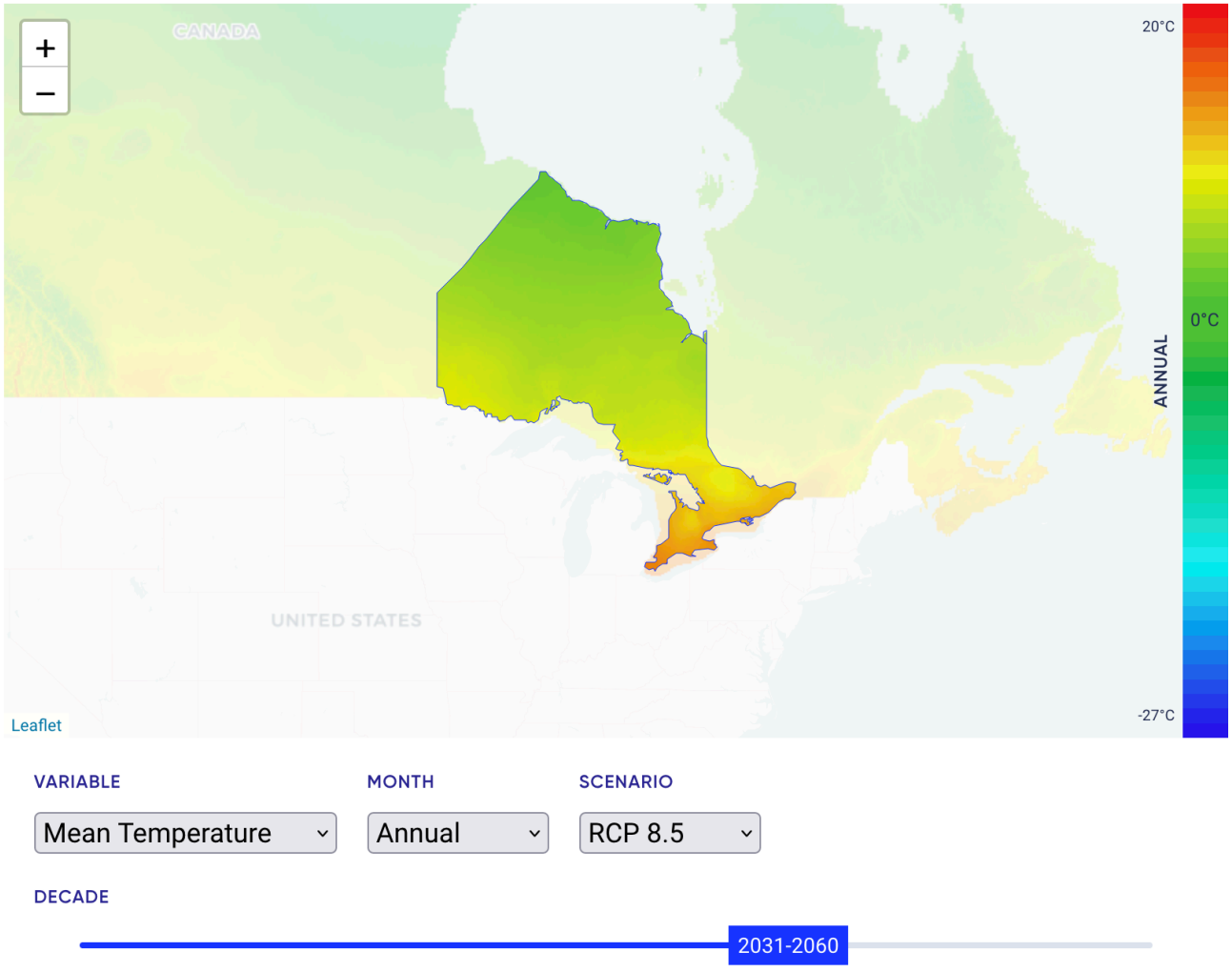

Figure 3.1: Interactive regional map of Ontario that draws from climatedata.ca and visualizes various climate variables from 1980 to 2100 using a high-emissions RCP 8.5 scenario. Source: climatedata.ca.

Gradual changes in mean climate conditions combined with changes in the frequency and magnitude of extreme weather events drive impacts that are having, and will continue to have, predominantly negative effects (Cohen et al., 2019; Zhang et al., 2019). The impacts associated with a changing climate have become

more apparent in daily life, increasing risks to social, economic and ecological systems (Government of Ontario, 2015a; 2011a). While Ontario's capacity to undertake adaptation actions to address these risks is relatively high in terms of institutional, technical, human and financial resources, this capacity has not yet been widely mobilized. This is despite clear recognition of the imperative of proactively managing the risks associated with climate change through effective adaptation (Environmental Commissioner of Ontario, 2018a).

3.1.1 Geography

Ontario's diverse landscapes, topography and natural resources help shape social, economic and cultural characteristics across the province (*see* Figure 3.2). The climate ranges from sub-Arctic in much of the north to hot-summer humid continental in the southern tip of the province near Windsor. Climate change impacts and adaptation capacity will differ across landscapes in Ontario and within the context of regional social, economic, cultural and environmental diversity.

Figure 3.2: Map of Ontario's subregions. Source: Chiotti and Lavender, 2008.

This report characterizes Ontario as having three subregions. The South subregion extends from Point Pelee Island in the south to the Quebec border in east. It contains half of Canada's most densely populated metropolitan centres, including the Greater Golden Horseshoe Area (which includes the Greater Toronto and Hamilton Area (GTHA) and the Kitchener-Waterloo Region), and the cities of Ottawa and London. Most of Ontario's projected population growth will continue to be in urban areas, particularly within the Greater Toronto Area and primarily through migration (Ontario Ministry of Finance, 2021a). The region includes the Canadian portions of Lake Huron, Lake Erie and Lake Ontario, which are critical for regional shipping, industry, tourism and agriculture (Woudsma and Towns, 2017).

The Central subregion includes the cities of Sudbury, Thunder Bay, Timmins, Sault Ste. Marie and North Bay, and has a much lower population density compared to southern areas of the province. The communities within this subregion remain largely dependent on natural resource industries, as well as on smaller, emerging sectors such as financial and business services, research and innovation, construction and tourism (Conteh, 2017). The region contains over two-thirds of the province's highway lines, which along with the rail network, provide important economic and social linkages between communities (Woudsma and Towns, 2017).

The North subregion, whose boundaries are consistent with those of the Far North as defined in the *Far North Act* (Government of Ontario, 2010), is sparsely populated. Despite covering 42% of the area of Ontario, this subregion contains only 0.17% of the province's population (Ontario Ministry of Indigenous Relations and Reconciliation, 2017). It is primarily populated by small First Nation communities that rely on subsistence practices and winter road access in order to acquire necessary resources (Ontario Ministry of Indigenous Relations and Reconciliation, 2017). Extending to the coasts of Hudson Bay and James Bay, the subregion includes areas with continuous and discontinuous permafrost and peatlands that sequester large amounts of carbon dioxide (McLaughlin and Webster, 2014). If disturbed, peatlands can release stored carbon into the atmosphere, reversing the carbon sequestration process and enhancing global warming. There are relatively few social, economic or ecosystem similarities between the North subregion and the Central and South subregions of the province.

3.1.2 Social and demographic profile

Ontario has a population of 14.7 million people and its population was the fastest growing amongst Canadian provinces as of July 2020, growing by 1.3% over the preceding year (Ontario Ministry of Finance, 2021b). The rate of population growth varies across the province, with populations in urban centres of the South subregion growing faster than those in the Central and North subregions, which are remaining stable or declining in some areas. These trends are expected to continue to mid-century under a medium-growth scenario, with the provincial population projected to grow by 35.8% (5.3 million people) over the next 25 years, largely resulting from increased net migration (Ontario Ministry of Finance, 2021c). Climate change will amplify existing social and economic stressors in high population urban centres (Wuebbles et al., 2019).

More than 374,000 people in Ontario are registered Indigenous Peoples, including First Nations, Métis and Inuit; of this number, about 116,000 people speak Indigenous languages (Statistics Canada, 2017). The Indigenous population is distributed across the province, with about one-third living in large population centres, such as Thunder Bay, Sudbury, Sault Ste. Marie, Ottawa and Toronto (INAC, 2018; Statistics Canada,

2017). Over one-quarter of Ontario First Nations Peoples live in remote communities of the North subregion that are only accessible by air or winter roads, two modes of travel that are highly dependent on weather and climate conditions (Ontario Ministry of Indigenous Relations and Reconciliation, 2017).

3.1.3 Economic profile

The diversity of economic activity across the province's subregions contributes greatly to the strength of Ontario's overall economy (Ontario Chamber of Commerce, 2020). Goods-producing and service sectors are primary contributors to the provincial economy, with the large metropolitan areas of the South subregion experiencing the highest employment growth rate (Government of Ontario, 2021a). Efforts to diversify resource-dependent economies and to build overall resilience include expanding the service and manufacturing sectors and enhancing ecosystem resilience (Government of Ontario, 2011b). For parts of the North subregion, particularly in the chromium-rich "Ring of Fire" area, newly discovered diamond and metallic deposits present unprecedented opportunities for economic development, with associated concerns about impacts on cultural practices and ecosystems (Chong, 2014).

3.1.4 Chapter approach

Building on the findings of previous assessments, this chapter identifies climate change impacts and risks specific to Ontario, evaluates adaptation progress across the province, and reports on knowledge gaps and emerging issues. The chapter assesses the knowledge base pertaining to both impacts and adaptation in Ontario, which has grown substantially since completion of the 2008 national assessment report (Chiotti and Lavender, 2008). Ongoing research continues to strengthen the evidence base and, while literature on risks and impacts still dominates, research focused on adaptation and resilience has increased considerably over the past decade (Brinker et al., 2018; Zeuli et al., 2018; AECOM, 2015; Chu, 2015; Lemieux et al., 2013).

Academic and other literature sources have been supplemented by input received through engagement sessions held with key stakeholders and practitioners across the province. The Key Messages reflect the social, economic and ecological diversity of Ontario, as well as the breadth of climate change impacts.

3.2 Ontario's infrastructure is vulnerable to climate change

As a result of interdependencies between multiple infrastructure types, climate change and especially extreme climate events can have cascading economic and social impacts. Flooding in the highly populated southern subregion, and impacts on winter roads in the northern subregion of the province demonstrate the range of risks. Targeted approaches to better understand the threats, and reduce infrastructure vulnerability are being used across the province.

Economies and society depend on well-functioning and resilient infrastructure for the continued delivery of critical services. Recent examples of infrastructure failures in Ontario, especially related to extreme rainfall and flooding, highlight both economic and social impacts. In the northern parts of the province, transportation infrastructure, in particular winter roads, are at risk. Local and regional governments in Ontario are starting to address the associated risks through risk assessments, asset management and design practices, emergency response planning, and strategic planning, including low impact development, that explicitly consider future climate conditions. Addressing the interdependencies that exist between different types of infrastructure, such as water, transportation, energy and telecommunications, is increasingly recognized as important to successful adaptation.

3.2.1 Introduction

Ontario's communities vary in size, population, geography and social fabric (*see* Sections 3.1.1 and 3.1.2). The infrastructure supporting these populations and economies varies in age and performance and will require significant investments in the coming decades (Canadian Infrastructure Report Card, 2019). These investments, encompassing maintenance, repair, reconstruction and new construction, present opportunities for climate change adaptation. Accounting for climate change risks in infrastructure renewal and upgrades yields broad and long-term social, environmental, and economic benefits (Adaptation to Climate Change Team, 2021; Canadian Climate Institute, 2021).

Widespread damage from extreme events in Ontario (*see* Section 3.2.2), including to human health and safety, has highlighted the vulnerabilities of infrastructure to climate change. This section focuses on flooding in southern Ontario and the impacts of climate change on winter roads in the north. It then discusses how adaptation is advancing across the province, through the application of infrastructure risk assessments and incorporation of climate change into infrastructure asset management. It concludes with a discussion on the importance of considering independencies between different types of infrastructure when planning for adaptation.

3.2.2 Flooding

Climate impacts with the highest documented costs and frequency in Ontario include flooding related to extreme rainfall, rainfall on frozen ground, rapid snow melt and ice jams (Moudrak and Feltmate, 2019;

Farghaly et al., 2015; Boyle et al., 2013). Extreme rainfall intensity is increasing in Ontario (Coulibaly et al., 2016; Soulis et al., 2016; Mekis et al., 2015; Shephard et al., 2014; Cheng et al., 2012; Paixao et al., 2011), as it is in adjacent regions in the United States (Easterling et al., 2017; Walsh et al., 2014). Non-climatic stressors, such as urban growth and land-use changes, also serve to increase the risks associated with flood events in Ontario (Henstra et al., 2020; Oleson et al., 2015).

Flood-related damage to infrastructure has been a primary driver of the increases in both insured and uninsured losses across Ontario and in many other parts of Canada (Moudrak and Feltmate, 2019; Feltmate et al., 2017; Moghal and Peddle, 2016; IBC, 2015). Flooding events in cities have interrupted business activity and caused hardship and anxiety among residents (Manning and Clayton, 2018; Decent and Feltmate, 2018; Moudrak and Feltmate, 2017). The rising costs associated with flooding in Canada are estimated to be accompanied by significant productivity losses (Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020; Davies, 2016). While reporting on insured losses paints a picture of high costs from urban flood events (*see* Table 3.1; Robinson and Sandink, 2021), additional uninsured damages increase the magnitude of total losses and are often unknown. However, estimates by the Insurance Bureau of Canada suggest that for every dollar of insured loss, there are three to four dollars of uninsured losses, which are borne by homeowners, business owners and governments (Moudrak et al., 2018).

Table 3.1: Examples of Ontario cities that have experienced extreme weather events in the past decade leading to significant insured losses

CITY	EVENT DATE	INSURED LOSS
Toronto	July 8, 2013	$1.024 billion
Windsor/Tecumseh/Essex	August 28 and 29, 2017	$177 million
Windsor/Tecumseh	September 28, 2016	$165 million
Hamilton, Ottawa	July 2012	$104 million
Greater Toronto Area	August 2014	$84 million

Source: Adapted from Robinson and Sandink, 2021.

Given the vulnerability of Ontario's infrastructure to extreme precipitation and flooding, adaptation approaches frequently involve the use of updated rainfall Intensity-Duration-Frequency (IDF) curves that determine the probability of a given rainfall event occurring (Simonovic et al., 2017; IBI Group, 2016; Soulis et al., 2015; Shephard et al., 2014). Methods to adjust IDF curves to account for climate change vary (Schardong et al., 2020; Soulis et al., 2016) and can yield significantly different results. User-friendly Web interfaces (Ontario

Ministry of Transportation, 2016; Schardong et al., 2020) and other technical guidance (Canadian Standards Association, 2019) are available for engineers and others to access updated IDF data, helping to facilitate the consideration of changing climate conditions in infrastructure-related decisions (Switzman et al., 2017; Sehgal, 2016; Soulis and Sarhadi, 2016; Solaiman and Simonovic, 2011).

To address extreme rainfall and flood risk, municipalities have traditionally employed end-of-pipe solutions to deal with stormwater. However, in recent years there has been an increase in the use of permeable surfaces and natural infrastructure to help control larger amounts of water (quantity) and to filter the water that recharges sub-surface aquifers (quality) (*see* Ecosystem Services chapter of the National Issues Report; Eckart et al., 2017; Environmental Commissioner of Ontario, 2017, 2016). Hamilton, Toronto, Thunder Bay, London, Newmarket and many other Ontario municipalities and conservation authorities have been actively promoting climate change adaptation through low-impact development (LID), master planning and watershed adaptation strategies (Henstra et al., 2020). Successful LID pilots include the use of permeable pavement, bioswales, rain gardens, green roofs, infiltration trenches and other forms of stormwater management that can be particularly valuable in limiting the impacts of smaller event storms (*see* Cities and Towns chapter of the National Issues Report). Natural areas like ponds, wetlands and vegetated areas are increasingly being viewed as tools for flood prevention and have numerous environmental and social benefits (e.g., for biodiversity and water quality), the value of which is highlighted in robust total economic value assessments (Moudrak et al., 2018).

Forty-four Ontario municipalities have combined sewer overflow (CSO) systems that release untreated or partially treated sewage into receiving lakes and rivers, and that are at higher risk of surcharging during flooding due to inadequate design standards at the time of construction, increased impervious surfaces and urban growth (Environmental Commissioner of Ontario, 2018b). As municipalities seek to replace outdated CSO systems and improve stormwater infrastructure, consideration of projected increases in the frequency and magnitude of flooding events will significantly reduce the risk of sewer backup and damage in homes, and the accompanying human health risks (Kovacs et al., 2014).

3.2.3 Transportation in Northern Ontario

Compared to more southerly and more densely populated areas of Ontario, infrastructure in the North subregion of Ontario services smaller, more dispersed and less populated communities, which are mostly Indigenous. Transportation infrastructure, which includes winter roads and air strips, is particularly crucial for the movement of goods and services into isolated communities. Warmer winters and temperature variability make winter road construction and maintenance difficult affecting road stability and safety, and ultimately impacting the supply of fuel, food and other staples (Hori et al., 2018a; 2018b).

Winter roads in northern Ontario provide overland connection to provincial highways and railway systems (*see* Figure 3.3). Winter roads reduce transportation costs of goods, compared to other alternatives, provide more affordable access to services (such as health care), support the self-sufficiency and well-being of people who travel for cultural and community events, and enhance access to remote communities and mineral resources. The roads are partly ice roads, in that portions of them cross rivers and lakes, while other sections traverse land. One metre of good quality ice can support loads of 50,000 kg (NWT, 2015). Over recent years, the

operating seasons have been shortening due to early thaw in the spring and warm spells in mid-season, as well as more frequent service disruptions due to variable weather events. These have resulted in softening of the road surface, deteriorating driving conditions requiring slower speeds and smaller loads, increased operations and maintenance costs, and increased risks to health and safety (Barrette, 2018; IBI Group, 2016).

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Figure 3.3: Methods and routes for accessing communities in Northern Ontario, including access by air, boat, rail and numerous road types. Winter roads are shown using red broken lines. Source: Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry, 2019

While conditions for more northerly locations may remain suitable for ice road construction in Northern Ontario through the middle of this century, even under high emission scenarios, seasonal warming and variability in weather conditions will affect more southerly locations and may preclude a viable ice road season (Hori et al., 2018b). Warm spells, such as those reported by winter road operators (Barrette, 2018; Kimesskenemenow Corporation, Ontario National Assessment Engagement Sessions, 2018–2019), and the trend toward fewer days of extreme cold (e.g., average number of days of -25 °C or lower decreased from 79 days in the mid-1950s to 57 days in the mid-2010s; IBI, 2015) pose significant challenges for construction and maintenance.

A range of solutions is available to help manage risks to winter/ice roads in the Far North, including the following: 1) using ice-penetrating radar for determining adequate ice thickness; 2) establishing permanent creek and small river crossings at key locations; 3) realigning some sections of road to be on land that is less susceptible to flooding during thaws or winter rain; 4) realigning some sections of road to be in corridors that are suitable for later upgrading to all-season roads; and 5) consistently using the best possible construction and maintenance protocols (Barrette, 2018). Moving from roads to airships or hovercraft for transporting heavy loads continues to be discussed as an option (IBI Group, 2016). In addition to technical solutions, communities have considered other alternatives, including the possibility of having all-weather roads and increasing self-sufficiency with respect to consumables (Reid, 2015). Adaptation responses are ultimately at the discretion of the community and dictated by regional circumstances and capacity.

3.2.4 Climate change risk assessments

Climate change risk assessments are key tools for understanding infrastructure vulnerability and options to enhance resilience. Since 2007, more than 20 engineering-focused climate change risk assessments have been conducted in Ontario as part of a national effort to train engineers on how to consider climate change in infrastructure decisions (*see* Table 3.2). Most of these assessments were completed using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol, which is a systematic, risk-based approach to reviewing how different weather and climate drivers affect infrastructure performance and life expectancy (Engineers Canada, 2016). The protocol has also been adapted for application in First Nations communities (First Nations Infrastructure Resilience Toolkit (FN-IRT); Félio and Lickers, 2019) and is planned to be released in summer 2022. The resulting assessments reveal the thresholds at which different infrastructure systems will be compromised when exposed to extreme weather and climate variability, and validate the interdependencies between infrastructure systems. They also identify and prioritize locations and populations that are most vulnerable in terms of climate change impacts on infrastructure and related service disruptions (Zeuli et al., 2018). Furthermore, they help raise awareness about climate risks among senior managers (AECOM, 2015) and, more broadly (Chiotti et al., 2017), signal the need for collaboration and coordination regarding adaptation responses, and serve as a catalyst for the creation and implementation of adaptation measures (Chartered Professional Accountants of Canada, 2015a; 2015b). Risk assessments are usually the first step in developing a comprehensive climate change adaptation strategy (*see* Case Story 3.1).

Table 3.2: PIEVC infrastructure vulnerability assessments completed in Ontario

INFRASTRUCTURE TYPE	LOCATION OF ASSESSMENT	REFERENCE
Energy	Toronto	AECOM (2012)
	Toronto	AECOM (2015)
	Ottawa	Stantec (2019)
	Province-wide	Toronto Region Conservation Authority (2015)
Transportation	Greater Sudbury	R.V. Anderson Associates Limited (2008)
	Toronto	GENIVAR Inc. (2011a)
	Toronto	AECOM, TRCA, and RSI (2016)
Water and Wastewater	Toronto	GENIVAR Inc. (2010)
	Prescott	GENIVAR Inc. (2011b)
	Welland	AMEC (2012)
	Leamington/Kingsville/Essex	GENIVAR Inc. (2013)
	GTA/Mississauga	Greater Toronto Airport Authority (2014)
	Akwesasne First Nation	Stantec (2017)
	Ottawa	R.V. Anderson Associates Limited (2017)
	Windsor	Landmark Engineers Inc. (2019)
	Moose Factory / Moose Cree First Nation	Stantec (2018a)
Food Services	GTA	Zeuli et al. (2018)
Buildings	Ottawa	HOK Canada (2008)
	Southwest Ontario	Golder Associates (2012)
	Oneida Nation of the Thames	Stantec (2018b)
	Kasabonika Lake First Nation	Stantec (2020)
Natural Infrastructure	GTA	Risk Sciences International (2018)
Ports	Toronto	AECOM (2019)

Case Story 3.1: The Metrolinx adaptation strategy

Metrolinx is a crown corporation responsible for the multimodal transportation system in the Greater Toronto and Hamilton Area (GTHA). A leader in adaptation in the transportation sector, the corporation designed the 2018 Metrolinx adaptation strategy built upon a vulnerability assessment undertaken by an interdisciplinary team using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (AECOM et al., 2016) and a Planning for Resilience report (Chiotti et al., 2017). The strategy outlines seven key adaptation measures for improving resiliency of rail transportation to weather extremes and changes in climate (Metrolinx, 2018). These measures include the following:

1. Improving infrastructure, such as enhancing and monitoring embankments, incorporating of low impact development (LID), and increasing culvert size and stormwater capacity to reduce risks of flooding and washouts;
2. Using a higher preferred rail laying temperature of 37.8 °C as the revised construction standard to preheat tracks, reducing the risk of track warping and buckling ("sun kinks") during heat waves;
3. Improving monitoring, such as weather forecasting, ballast integrity sensors (to detect washout in the free-draining aggregate that supports the railway track), and real-time stream levels and flood conditions at track level, to reduce vulnerability to extreme precipitation events;
4. Developing a corporate-wide Winter Plan to prepare for severe snowfall, freezing rain and extreme winter temperatures to allow for operations to be sustained;
5. Enhancing emergency response and operating procedures during and after extreme weather events;
6. Updating operational protocols for trains in case of high water conditions caused by extreme precipitation events and flooding; and
7. Upgrading standards for back-up power generation at stations and facilities to ensure power supply during prolonged blackouts caused by extreme weather events.

The Metrolinx adaptation strategy was one of the first of its kind for rail infrastructure. The plan development process included elements of asset management, design practices, emergency response planning and preparedness, and regional and strategic planning, along with engagement and education activities. The process and resulting plan can be considered as good practice for other Ontario and Canadian metropolitan settings.

3.2.5 Asset management

Municipalities and other infrastructure owners and managers have begun to incorporate adaptation into their asset management practices (*see* Cities and Towns chapter of the National Issues Report; Kenny et al., 2019; Kenny et al., 2018; Metrolinx, 2018; Federation of Canadian Municipalities, 2017; Félio, 2017; Ontario Chamber of Commerce, 2017; Ernst and Young, 2016; Félio, 2016). New statutory and regulatory requirements have been an important driver of this activity. Of particular importance is the *2015 Jobs and Prosperity Act*, with

regulation 588/17 requiring municipalities to develop and implement an asset management plan and supporting policies for municipal infrastructure (Ontario e-Laws, 2018). The regulation also requires municipalities to "consider actions that may be required to address vulnerabilities that may be caused by climate change…" (Ontario e-Laws, 2018). Another key driver has been the Federation of Canadian Municipalities Municipal Asset Management Program, which since 2016 has funded 157 projects in Ontario focused on improving asset management practices (Federation of Canadian Municipalities, 2020). Integrating climate change into the planning, maintenance, renewal and rehabilitation cycle of infrastructure assets ensures their longevity and helps to safeguard service levels for communities (*see* Figure 3.4; Canadian Infrastructure Report Card, 2019; 2016).

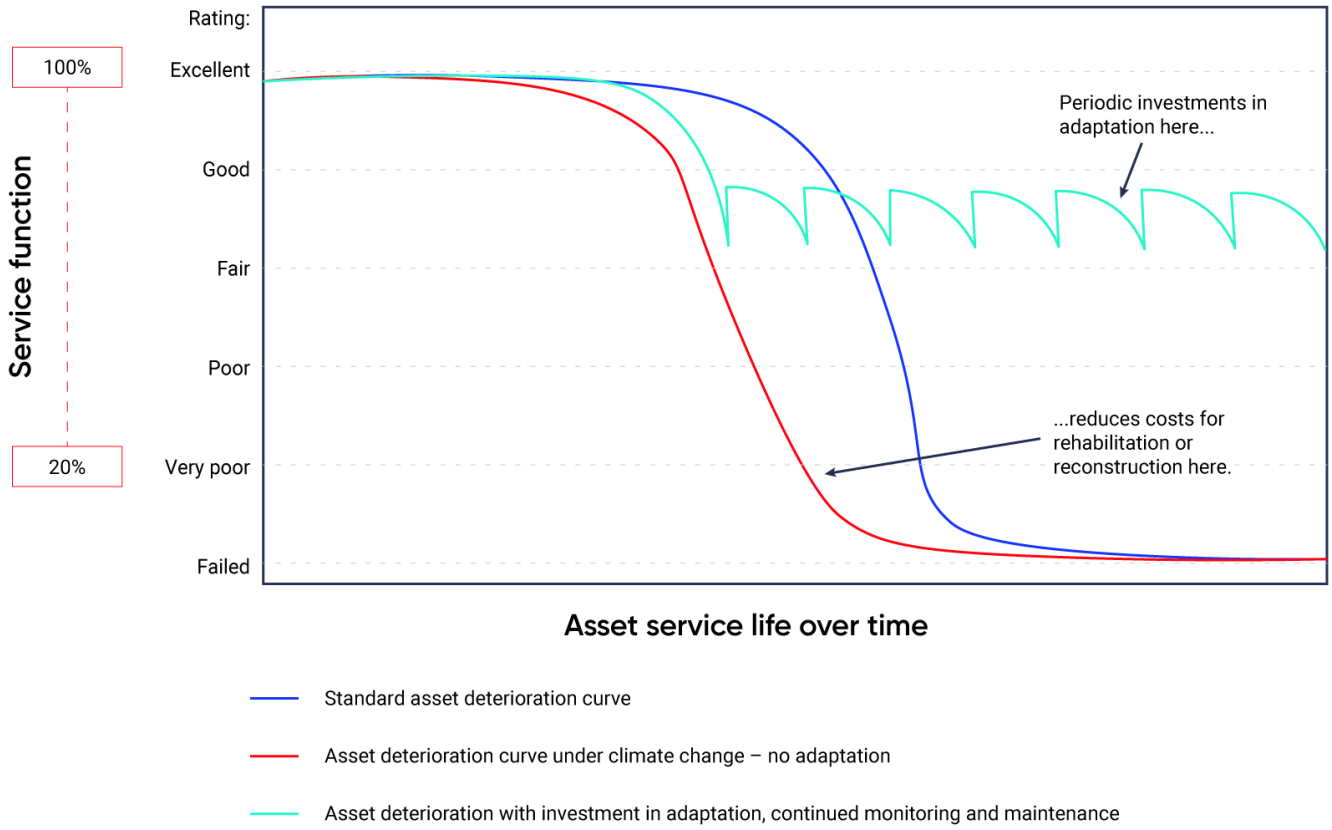

Figure 3.4: Example of asset deterioration curve for roads showing how reoccurring, planned investments in adaptation and the preservation of assets during the initial degradation phase (e.g., from "excellent" to "good") are significantly more cost-effective than reactive management through rehabilitation or reconstruction for conditions ranging from "fair" to "very poor". Source: Canadian Infrastructure Report Card, 2019; 2016.

Under the *Environmental Assessment Act*, the Ontario Ministry of Environment, Conservation and Parks (MECP) has issued guidance on how best to consider climate change in the environmental assessment process. Additionally, the Ontario Provincial Policy Statement 2014 states that "planning authorities should promote green infrastructure" (Ontario Ministry of Municipal Affairs and Housing, 2020) that delivers additional benefits in the areas of human health and reduction of greenhouse gas emissions.

3.2.6 Interdependencies

Ontario's water and wastewater, transportation, energy and telecommunications infrastructure, buildings and other forms of infrastructure are highly interconnected. In many cases, interdependencies exist, which means that the safe and consistent operation of one asset contributes to a similarly safe and consistent operation of another. Disruptions, caused by climate events or other factors, can lead to multiple and compounded infrastructure failures, affecting the delivery of critical services and routine business operations (*see* Sector Impacts and Adaptation chapter of the National Issues Report). Infrastructure interdependencies are not just physical, but also pertain to ownership, responsibility and liability. Businesses are often shared users and owners of infrastructure, and while they can take steps independently to be more climate resilient (through, for example development of business continuity plans, acquiring suitable insurance, etc.), they still remain dependent on the climate resiliency of neighbouring services. Decision making in such situations requires tools and planning processes that incorporate complex interdependencies (Bondank and Chester, 2020; Farhad et al., 2019; Zeuli et al., 2018; AECOM 2017).

The City of Toronto led a high-level risk assessment to identify interdependencies and adaptation responses that span multiple sectors (hydroelectricity, transportation, water and wastewater, food and agriculture, etc.) (AECOM, 2017). One example highlighted how a natural gas provider and district energy supplier are dependent on Toronto Hydro for electricity, and Toronto Hydro in turn relies on infrastructure like the City's road network and stormwater system, with the result that flooding associated with extreme rainfall could cascade through all electricity assets and lead to failure (*see* Figure 3.5; AECOM, 2017).

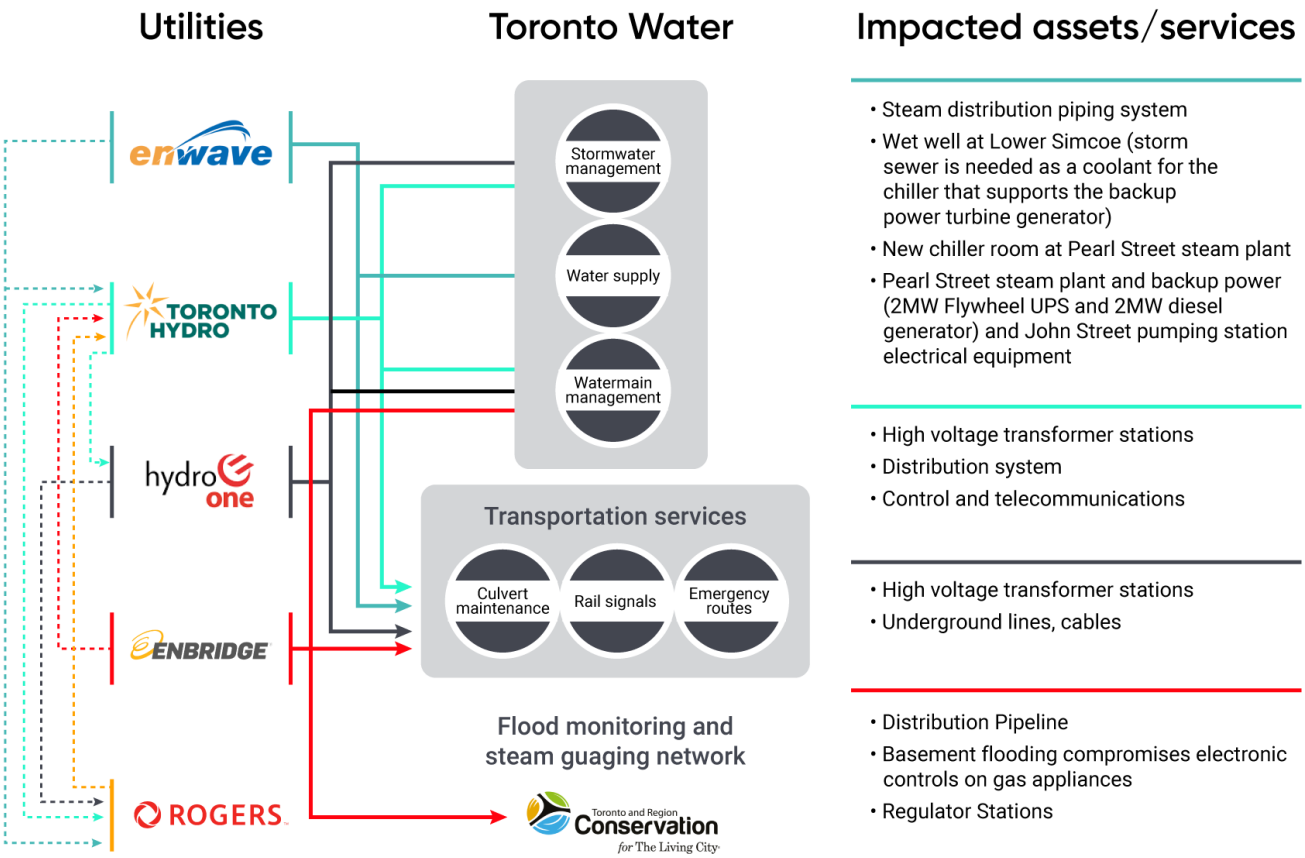

Figure 3.5: Interdependencies in utilities within the Greater Toronto Area. Source: AECOM, 2017.

The Toronto risk assessment exemplifies the collaboration required to mobilize adaptation. It sheds light on the cascading impacts of climate change, as well as efficiencies in planning that can make adaptation more cost-effective. The assessment also highlighted the need for information sharing protocols, detailed engineering-level investigations, enhanced funding and more proactive infrastructure planning and policy development (AECOM, 2017).

3.3 Nature-based approaches help address climate change impacts on biodiversity and ecosystem services

Climate warming has driven and will continue to drive changes to species and create new opportunities for invasive species. Impacts on biodiversity are magnified through the cumulative effects of climate change, habitat loss, urbanization, pollution and other threats. Actions to mainstream nature-based solutions, including the establishment of protected areas, such as Indigenous Protected and Conserved Areas, can help maintain ecosystem services and reduce climate change risks, as well as mitigate climate change.

Ontario includes a wide range of ecosystems, from forests, wetlands and grasslands in the south, to tundra, expansive wetlands, peatlands and coastal marshes in the Far North. These ecosystems provide important services to Ontarians, including provisioning services such as food and water, and regulating services such as flood and disease control. Changes in climate are placing added pressure on ecosystems, through changes to the composition, structure and function of ecosystems, changes to the geographic ranges of species, disruptions to the timing of life stage events and, in some cases, altering genetic diversity. In the absence of effective protection and restoration measures, heavily populated parts of the province and areas labelled for economic development could see additional declines in biodiversity and ecosystem services. Rapid and scaled-up interventions that target ecological resilience and foster natural adaptation will help manage climate change risks and protect ecosystem services on which communities rely.

3.3.1 Introduction

Biodiversity is defined as "the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems" (United Nations Convention on Biological Diversity, 1992). Biodiversity includes the goods and services that ecosystems provide, including those on which humans depend for our survival, health, safety and/or prosperity (Ontario Biodiversity Council, 2015, 2011). Weather and climate combined with physical site conditions largely determine which species can survive and which cannot (Nituch and Bowman, 2013). Given the climate's relative stability over the past several millennia, entire ecosystems and their associated species have evolved to cope with prevailing climate and soil conditions (Brinker et al., 2018).

The Ontario Biodiversity Strategy recognizes climate change as one of the greatest threats facing biodiversity (Ontario Biodiversity Council, 2011, 2015). Existing stresses on terrestrial and aquatic ecosystems can be exacerbated by climate impacts, such as changes in the frequency and magnitude of extreme weather, the extent and duration of freshwater ice cover, vegetative phenology, breeding activity and insect emergence, with cascading effects on food webs. A number of other provincial strategies and programs address biodiversity and ecosystem impacts, including the Ontario Ministry of Natural Resources and Forestry (MNRF) Climate Change Adaptation Strategy (Ontario Ministry of Natural Resources and Forestry, 2017b), the Wetland

Conservation Strategy (Ontario Ministry of Natural Resources and Forestry, 2017c); and the 50 Million Tree Program (Forests Ontario, 2016).

3.3.2 Impacts and vulnerabilities

3.3.2.1 Terrestrial ecosystems

Natural selection pressures under climate change and other human-created stresses are changing the structure and composition of many of Ontario's ecosystems, as well as the socio-economic services and functions that they provide (Brinker et al., 2018; Ontario Ministry of Natural Resources and Forestry, 2017b). Ontario species already demonstrating shifts in distribution include the common opossum, white-tailed deer, southern flying squirrel and Nodding Ladies' Tresses orchid (Kennedy-Slaney et al., 2018; Nituch and Bowman, 2013). Peatlands in the northern subregion store immense amounts of carbon, providing a regulating ecosystem service (*see* Ecosystem Services chapter of the National Issues Report). Warming winter temperatures causing permafrost thaw, enhanced microbial action and peat decay in the soils will lead to further loss of carbon to the atmosphere (Turetsky et al., 2020; Natali et al., 2019; McLaughlin et al., 2018). Drier conditions in peatlands also increase fire risk with long-lasting smouldering and subsequent carbon release (McLaughlin et al., 2018; Turetsky et al., 2014).

Warming will be greatest in parts of the North subregion (*see* Figure 3.1), where potential northward migration of terrestrial species is limited by Hudson Bay and James Bay. Ecosystems located further south, most notably in the mixedwood plains ecozone (southwestern Ontario, and parts of central and northeastern Ontario) will experience less warming, but impacts will be exacerbated by habitat fragmentation from increasing land-use pressures and pollution in the human-dominated landscapes of southern Ontario (Brinker et al., 2018; McLaughlin et al., 2018; Ontario Ministry of Natural Resources and Forestry, 2017b; 2017c; McLaughlin and Webster, 2014;Varrin et al., 2007). Species with generalist habitat requirements (e.g., raccoons, coyote and deer) and greater dispersal abilities are capable of colonizing new areas, diversifying food sources and thriving within broader thermal thresholds, and will manage to adapt to changing conditions. This also includes invasive terrestrial and aquatic species that will be able to thrive and expand their ranges, contributing to a changed and possibly simplified ecosystem structure (McDermid et al., 2015a; Government of Ontario, 2012). Species with poor dispersal capabilities, or with specialized and narrow habitat requirements, will be the most vulnerable to changing conditions (Ontario Ministry of Natural Resources and Forestry, 2017b; Nituch and Bowman, 2013; Government of Ontario, 2012). Other species, such as types of fish, insects and plants, will decline in population as temperature or moisture conditions approach or exceed their tolerance limits (Brinker et al., 2018).

Climate change will influence changes in species interactions, including competition and predation, and impacts from diseases, pests and invasive species. Problems occur when climate change has different effects on predator and prey species, producing a mismatch in timing between life cycle events that limit food availability, ultimately affecting successful breeding for many species (*see* Ecosystem Services chapter of the National Issues Report; Guzzo and Blanchfield, 2016; Nantel et al., 2014; Joyce and Rehfeldt, 2013; Klaus and Lougheed, 2013). In the North and Central subregions, the distribution of deer, moose and caribou is expected

to change substantially over the current century, in part because of changes in temperature and precipitation. White-tailed deer distribution is limited at its northern boundary by the severity of winter climate. Studies suggest that warmer winter temperatures and less deep snow will remove this limitation and contribute to expanding the northern distribution of white-tailed deer in Ontario by 2100 (Kennedy-Slaney et al., 2018). Even small changes in the abundance of common species can have cascading effects on ecosystem composition and structure, and on the services that those ecosystems provide (Brinker et al., 2018; McDermid et al., 2015b; Government of Ontario, 2012).

The cumulative impacts of climate change, habitat loss and fragmentation, and other drivers will continue into the future, resulting in declining viability of some species in Ontario (Ontario Ministry of Natural Resources and Forestry, 2017b). Where landscape connectivity is limited, vulnerable populations have an increased risk of becoming locally or regionally extinct (Nituch and Bowman, 2013). For example, the Great Lakes and the Saint Lawrence River are significant barriers for wildlife; with increasing habitat fragmentation from urban and agricultural development, connectivity for many terrestrial species will decline. Even generalist native species, such as the bobcat, are experiencing disrupted gene flow where landscape connectivity is low (Marrotte et al., 2020). The extent to which species can navigate routes through the Great Lakes region will be important for the future biodiversity of areas north of the Great Lakes. Species living in warmer habitats to the south of the Ontario-U.S. border will continue to follow shifting temperature zones into Ontario, ultimately leading to the emergence of novel ecosystems (Nituch and Bowman, 2013). Impacts on biodiversity may include reorganization of species, replacement of dominant or keystone species, and pass-through effects on higher trophic levels (Nituch and Bowman, 2013).

3.3.2.2 Aquatic ecosystems and watersheds

Aquatic species have adapted to temperatures that optimize their physiological processes (Brinker et al., 2018; Alofs et al., 2014). Changes in precipitation patterns alter the amount of available habitat for many species, and increasing water temperatures modify the thermal regimes of lakes, rivers and wetlands (Minns et al., 2014; Chu, 2015). Increasing water temperatures can have cascading effects that alter the growth, reproduction and survival of aquatic organisms. As temperatures continue to warm, fish species will migrate northward to follow their favoured climate, resulting in increased growth, survival and abundance for warm-water species such as smallmouth and largemouth bass, but decreases in cold-water species such as lake trout (Edwards et al., 2016; Guzzo and Blanchfield, 2016; Sharma et al., 2009). The warming trend in Ontario has already facilitated the range expansion and establishment of warm-water fish species in northern regions of Ontario (Alofs et al., 2014), and has caused shifts in the abundances of different species within assemblages (Staudinger et al., 2021).

Changes in Ontario's climate are affecting the timing of important life stage events, such as spawning or lake-riverine migrations, and selecting for certain evolutionary traits (Myers et al., 2017; Lynch et al., 2016). Such phenological shifts have been recorded among several fish species, including smallmouth bass in Algonquin Park, whose spawning is advancing significantly earlier in the spring (Ridgway et al., 2017). These changes alter the competition and predator-prey relationships among wildlife and increase the likelihood of invasive species establishment (Brinker et al., 2018; Chu et al., 2018b; Sharma et al., 2009).

Extreme high and low water levels in lakes affect the amount of suitable habitats for native plant and animal species, particularly in wetland environments. Coastal wetlands in southern Ontario are particularly vulnerable to climate change, which adversely impacts wildlife habitat availability, bird migration patterns and overall ecosystem health (Chu et al., 2018b; Ontario Ministry of Natural Resources and Forestry, 2017c; Chu, 2015; McDermid et al., 2015b).

Aquatic species have an inherent capacity to adapt to a certain amount of ecological change because of their genetic and behavioural plasticity (Kelly et al., 2014; Stitt et al., 2014); however, the pace of ecological change associated with climate change is extending beyond the tolerance range of many species (Moritz and Agudo, 2013; Quintero and Wiens, 2013). Improved understanding of the natural variation in aquatic ecosystems and their capacity to rebound from perturbations (e.g., Gutowsky et al., 2019; van Zuiden et al., 2016; Stitt et al., 2014; Gronewold et al., 2013 and Sharma et al., 2007) helps to inform and prioritize effective adaptation measures.

3.3.3 Resiliency and adaptation

More than 14% of the 15,800 plant and animal species in Ontario that have been assessed by scientists are considered vulnerable, rare or rapidly declining, and their future survival is uncertain (Canadian Endangered Species Conservation Council, 2016). Opportunities to enhance the resilience of species to a changing climate vary depending upon available habitat, species vulnerability and available management tools (*see* Box 3.1). Integrating species vulnerability assessments into habitat and species management, restoration and species recovery planning can help to enhance resilience, as can judiciously applied assisted migration (*see* Section 3.5.3) in forest and other habitat restoration activities (Brinker et al., 2018; Douglas et al., 2014; Lemieux et al., 2014; Chu and Fischer, 2012; Gleeson et al., 2011; Ste-Marie et al., 2011).

Box 3.1: Assessing species vulnerability

The NatureServe Climate Change Vulnerability Index (Young and Hammerson, 2015) was used to assess the relative vulnerability to climate change of 280 species in Ontario's Great Lakes Basin (Brinker et al., 2018; Young and Hammerson, 2015). The Index assesses species exposure to climate change, as well as sensitivity and adaptive capacity, in order to derive a vulnerability score (*see* Figure 3.6). The categories of the indexed scores range from "Insufficient evidence" and "Less vulnerable" to "Extremely vulnerable", and they are accompanied by statistically based confidence ratings (*see* Figure 3.7).

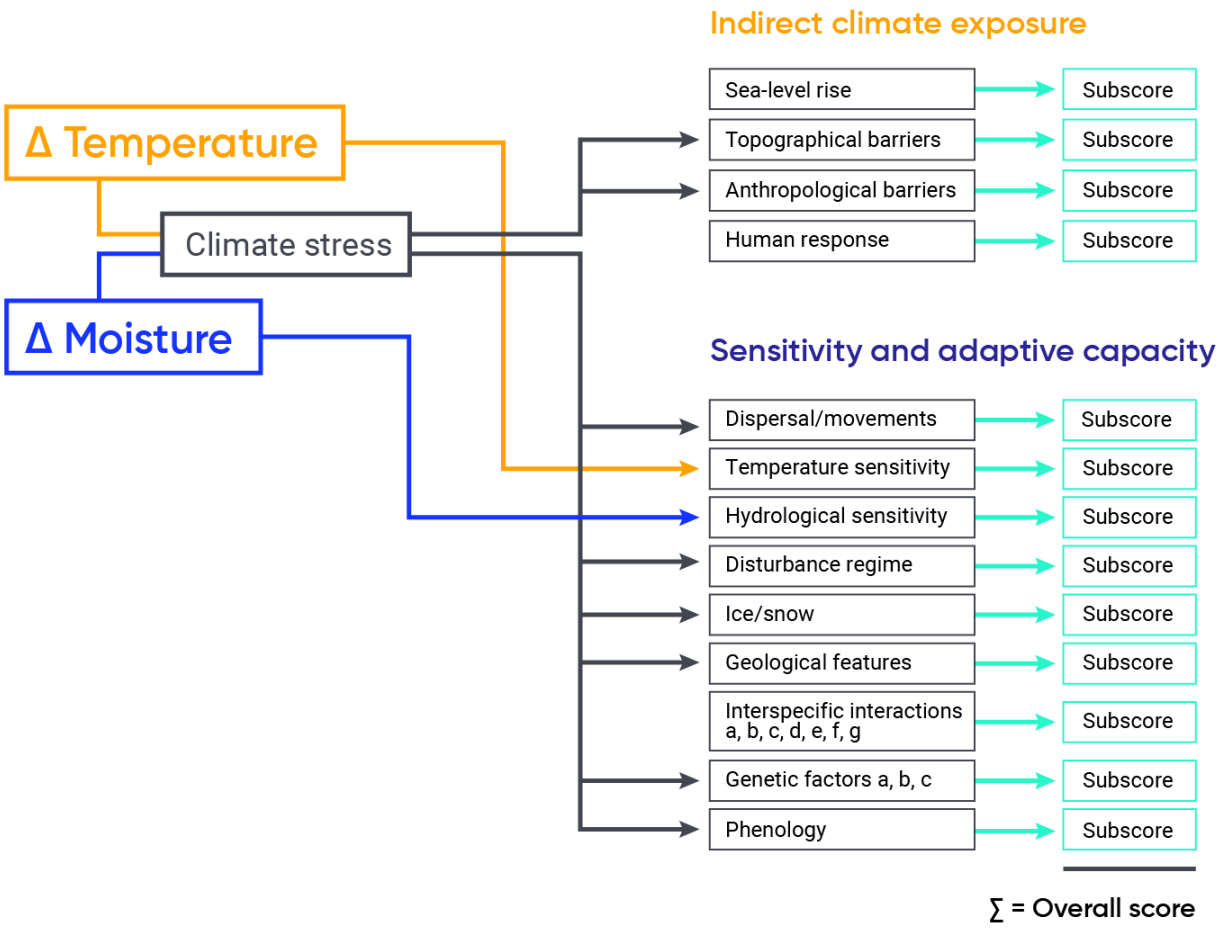

Figure 3.6: Determining factors of the Climate Change Vulnerability Index. Source: Young and Hammerson, 2015.

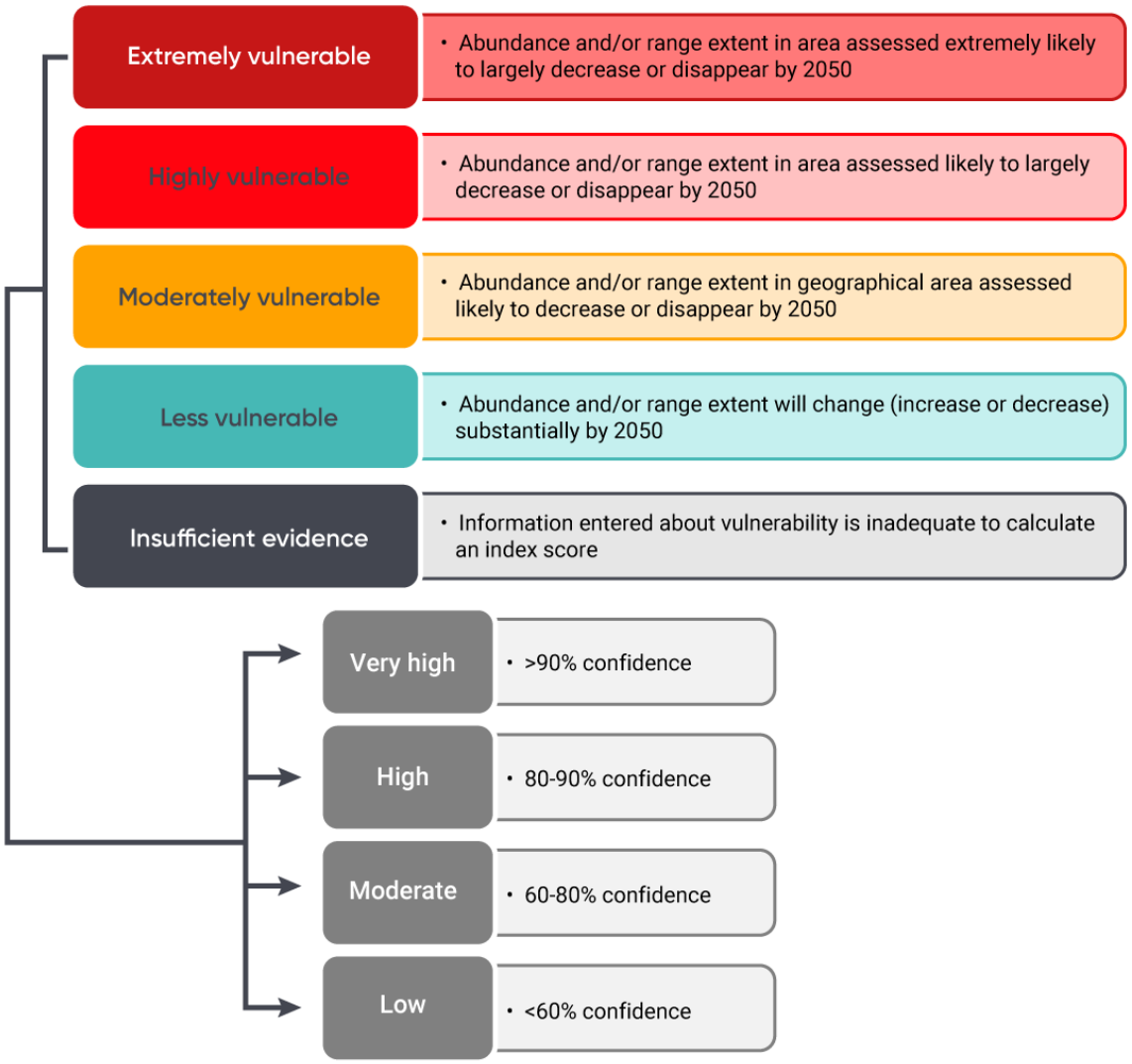

Figure 3.7: Climate change vulnerability indexed scores and confidence levels. Sources: Brinker et al., 2018; Young and Hammerson, 2015

Results showed that 175 of the 280 species assessed are vulnerable to climate change, of which 11 are extremely vulnerable, 49 highly vulnerable and 115 are moderately vulnerable. Molluscs, fish, amphibians and lichens were most vulnerable. Vascular plants and mammals varied widely in assessed vulnerability, while birds, insects and spiders, and reptiles were found to be the least vulnerable. The common risk factor for all groups was the species' past exposure to precipitation variations across their habitat range, and ultimately their ability to adapt to future hydrological changes within their niche. Other important factors include species' temperature tolerance, the ability of seeds to migrate, barriers to movement and habitat specificity (Brinker et al., 2018).

A number of guidance documents are available to assist ecosystem managers and practitioners to include climate change in planning and management practices (e.g., Environment Canada, 2013; Gleeson et al., 2011). Key approaches for enhancing ecosystem resilience include the following: protecting intact ecosystems; increasing connectivity through the protection and implementation of ecological corridors (*see* Box 3.2) and regional/urban biodiversity strategies; and strategically using native species suited to new locations and predicted climatic conditions in habitat restoration efforts. Actions that can boost the resiliency of aquatic ecosystems and organisms are as follows (Myers et al., 2017; Chu, 2015; Gleeson et al., 2011):

1. Restricting withdrawals of surface and groundwater from vulnerable lakes, rivers and wetlands;
2. Providing nest boxes or rehabilitating nesting habitats for vulnerable wetland birds;
3. Maintaining natural water levels in lakes and wetlands, and flow rates in rivers;
4. Restoring or enhancing riparian vegetation along stream shorelines;
5. Identifying and protecting refugia; and
6. Limiting human development and industrial activities.

Box 3.2: Assisting wildlife migration

Measures that keep wildlife safe from roads, such as fencing and dedicated wildlife tunnels and bridges, are critical infrastructure components that help achieve habitat connectivity objectives in Ontario (*see* Figure 3.8). Ontario continues to develop policies that direct municipalities to identify, conserve and link natural features for the movement of native plants and animals across the landscape to ensure the long-term protection of biodiversity in an era of rapid climate change.

Figure 3.8: First photo shows a wildlife overpass on Highway 69. Second photo shows a diversion fence in Bruce Peninsula National Park. The fence helps to direct wildlife towards an eco-passage, while the grating shown in the third photo maximizes the amount of natural sunlight inside, creating an attractive passage for species-at-risk. Source: First photo courtesy of Timercraft Consultation Inc. Latter photos courtesy of Christopher Lemieux.

3.3.3.1 Parks and protected areas

Ontario features a network of approximately 700 parks and other types of protected areas that include National and Provincial Parks, Conservation Reserves, Nature Conservancy of Canada (NCC) Sites and at least 40 other designations (Environment and Climate Change Canada, 2021; Ontario Ministry of Natural Resources and Forestry, 2012; Gray et al., 2009). These comprise about 10.7% of the province's total terrestrial area and provide important habitat for biodiversity, as well as space for recreation, research, monitoring and education.

Ecosystem resilience to climate change can be supported through performance targets for conservation, such as those within the 2020 Biodiversity Goals and Targets for Canada (biodivcanada, 2020). The Strategy sets targets for conservation of terrestrial and inland waters, as well as coastal and marine areas. In Ontario,

the Ontario Biodiversity Strategy also sets targets in areas that include engaging people, reducing threats, enhancing resilience and improving knowledge (Ontario Biodiversity Council, 2021; 2015; 2011). The federal government's reaffirmation of its commitment to protect 30% of land and ocean by 2030, and to ensure that action and investment for nature and climate change are central to COVID-19 recovery planning (Office of the Prime Minister, 2019), have implications for Ontario's conservation efforts.

A significant body of knowledge focuses on the impacts of climate change on species distribution and ecosystem structure and function (e.g., Chu et al., 2018a; Parker, 2017; Dove-Thompson et al., 2011; McKenney et al., 2010), and the implications for protected areas management (Barr et al., 2020; Gutowsky and Chu, 2019; Parker, 2018; 2017; Lemieux et al., 2014; Canadian Parks Council, 2013; Lemieux et al., 2011). The literature highlights that managing for climate change impacts on biodiversity and ecosystem function will require an adaptive, flexible, forward-looking and collective approach (Gross et al., 2016; Lemieux et al., 2010). This includes developing and sustaining relationships and communication networks among various levels of government, scientists and other partners, and increasing participation from Indigenous communities in all aspects of conservation planning and management (Lemieux et al., 2011).

Protected areas have fixed boundaries that cannot easily change as the ecosystems and species that they were established to conserve migrate in response to the changing climate. Therefore, enhancing connectivity between existing natural and protected areas is a key adaptation goal (Lemieux et al., 2011). Connectivity can be enhanced through the protection or restoration of "greenway" and "blueway" networks, such as natural corridors, riparian areas (zones between aquatic and dry-land habitat), rivers and lakes, or other habitats that connect natural areas (Andrew et al., 2014). Connectivity mapping for terrestrial ecosystems has been completed across Ontario and applied to multiple species to evaluate genetic connectivity for informing landscape planning and efforts to build ecosystem resilience (Marrotte et al., 2017). Such networks enable range shifts for certain species, as well as the exchange of genetic material, and enhanced resilience to cope with significant disturbance (e.g., large forest fires and pest outbreaks) and disruption by human activity (*see* Case Story 3.2).

Case Story 3.2: The Norfolk Sand Plain Natural Area

The Norfolk Sand Plain Natural Area in southwestern Ontario (*see* Figure 3.9) is home to more than 45 provincially, nationally or globally rare plants and animals—one of the highest densities of rare and endangered wildlife in Canada (Nature Conservancy of Canada, 2019). Long Point Provincial Park is a Provincially Significant Wetland,, an internationally recognized wetland under the Ramsar Convention, a UNESCO Biosphere Reserve and a nationally significant Important Bird Area.

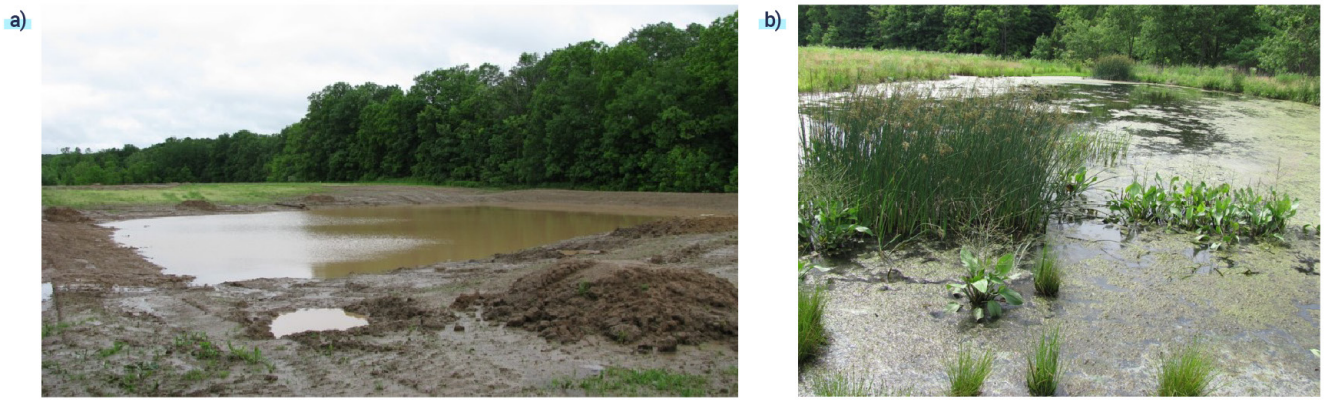

Figure 3.9: Pre (left) and post (right) photos of the Nature Conservancy of Canada Williams Wetland restoration project within the Norfolk Sand Plain Area. Source: Nature Conservancy of Canada, 2019.

The Nature Conservancy of Canada has been restoring agricultural fields in the area since 2006, improving connectivity between existing core areas. Wetland restoration has created additional habitat for species-at-risk, including the Blanding's turtle (*Emydoidea blandingii*). The wetlands also act as a staging area for migratory shorebirds and waterfowl. In addition to enhancing the climate resilience of the Norfolk Sand Plain Natural Area, the restored wetlands play a valuable role in protecting ecological services in the area. These include maintaining and improving water quality by filtering nutrients and sediment from overland flow, recharging groundwater, holding flood waters and reducing erosion. The natural area has become critical for conserving species and habitats unique to Canada's Carolinian Life Zone and for achieving conservation at a landscape level (Nature Conservancy of Canada, 2019).

In the Far North of Ontario, the provincial government and local First Nations are engaged in a process to jointly prepare community-based land-use plans that will designate areas for protection as well as areas for sustainable use (Government of Ontario, 2010). Many large areas of high regional and continental conservation value in North America lack formal protection, with the Hudson Bay Lowlands and Northern Forests of Ontario included in a list of biomes with the lowest rates of protection for high-value climate refugia and corridors (Stralberg et al., 2020).

Nature-based approaches that encourage the protection, sustainable management and restoration of natural or modified ecosystems and simultaneously provide human well-being and biodiversity benefits significantly improve the chances of successfully responding and adapting to climate change (Smith, 2020). Protection of Canada's most carbon-dense/high-biodiversity ecosystems has also been identified as the most effective nature-based approach for obtaining short-term results on immediate (by 2030) reduction in annual greenhouse gas emissions through the maintenance of carbon sinks for carbon storage (Smith, 2020). In addition to targeted protection, other approaches that would result in large benefits for biodiversity, as well as co-benefits for carbon storage include the following: growing 30% of managed forests that are currently over 60 years old to ecological maturity and protecting them; additional tree planting; and increasing the length of time between harvests.

Applying nature-based approaches will require collaboration between the Province, conservation authorities, municipalities, Indigenous communities and the broader public. The establishment of Indigenous Protected and Conserved Areas (IPCAs) in Ontario represent an opportunity for Indigenous governments to have a primary role in protecting and conserving ecosystems through Indigenous laws, rights, governance and knowledge systems, and such areas can support and encourage further research and capacity building (The Indigenous Circle of Experts, 2018). A Memorandum of Understanding has been reached between the Mushkegowuk Council and the Government of Canada to assess the feasibility of creating a National Marine Conservation Area (NMCA) in western James Bay and southwestern Hudson Bay (Parks Canada, 2021).

The combined understanding of climate change impacts and adaptation solutions that emerge from consideration of local knowledge, Indigenous Knowledge and Western science can serve to reduce climate risks to safety, property and infrastructure, while at the same time promoting the resilience of Ontario's ecosystems and communities. Establishing information networks to facilitate ongoing knowledge exchange within the conservation community is one of the most important practices that organizations can employ in an era of rapid climate change (Gross et al., 2016). Within Ontario, the overall organizational capacity to conserve biodiversity and foster the partnerships necessary to implement adaptation options is considered low (Barr et al. 2020; Office of the Auditor General of Ontario, 2020; Lemieux and Scott, 2011; Lemieux et al., 2010).

3.4 Adaptive management is key for addressing impacts in the Great Lakes Basin

The combined effects of climate change, land-use changes and other stressors are negatively impacting the Great Lakes Basin. Despite mechanisms to address complex governance challenges, adaptation efforts across the Basin remain relatively fragmented. Many communities have embraced adaptive management practices to address impacts in light of uncertainties in future changes.

The Great Lakes Basin is a region of high environmental, social and economic importance to Ontario. Climate change has resulted in a range of physical, chemical and ecological impacts on the lakes themselves, which are amplified by the impacts of urbanization, agricultural practices and other human activities. Seasonal lake ice cover and water levels both show high year-to-year variability, necessitating adaptation actions that address a range of future conditions. The international setting of the Basin necessitates the involvement of the Canadian and American national governments, as well as that of provincial, state and local governments in order to develop regional responses to climate change. While a number of functional governance mechanisms are in place, implementation of adaptation actions remains fragmented. Leadership is emerging from several municipalities employing adaptive management practices that involve continuous monitoring, evaluation and improvement of management plans. Strong and coordinated adaptation efforts across the Basin can help to protect communities, and to sustain the resources and services that the area provides.

3.4.1 Introduction

The Great Lakes Basin play a critical role in shaping Ontario's environmental, social, cultural and economic landscape. As a region, including both Canada and the U.S., the Great Lakes–Saint Lawrence Basin covers more than 765,000 square kilometres, contains 21% of the world's fresh surface water, and is home to more than 8.5 million Canadians (22% of the population) (Council of the Great Lakes Region, 2017). Surrounding communities rely on the freshwater resource for drinking water, recreation and tourism, manufacturing, fishing, agriculture and shipping industries.

Climate change is considered one of the greatest threats facing the Great Lakes Basin, exacerbating risks associated with land-use changes and other human activities, resulting in changes to the physical, chemical and ecological characteristics of the lakes, and presenting social and economic risks to surrounding communities (Brinker et al., 2018; Government of Ontario, 2016a; McDermid et al., 2015b). The widespread impacts of climate change have been well documented, as discussed in Section 3.4.2 (Great Lakes Integrated Sciences and Assessments (GLISA) and Environment and Climate Change Canada (ECCC), 2018; International Joint Commission Great Lakes Water Quality Board, 2017; McDermid et al., 2015b) and are projected to worsen over the coming decades (Bonsal et al., 2019; Derksen et al., 2019; Angel et al., 2018; GLISA and ECCC, 2018; McDermid et al., 2015b). The risks associated with climate change are presented in Annexes to both the Great Lakes Water Quality Agreement (Government of Canada and Government of the United States, 2012) and the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (Government of Canada and Government of Ontario, 2014). Solutions lie in coordinated and collaborative adaptation planning and management across the Basin.

3.4.2 Impacts and vulnerabilities

3.4.2.1 Environmental Impacts

The Great Lakes directly influence and regulate the regional weather by moderating seasonal temperatures and generating local precipitation through lake effects (Mortsch, 2016; McDermid et al., 2015b; Gula and Peltier, 2012). In recent years, the impacts of changing climate have been manifested through changes in ice cover and water temperatures, (Zuzek, 2020; Bonsal et al., 2019; Derksen et al., 2019; Byun and Hamlet, 2018; Di Liberto, 2018). Changes in ice cover and water levels have been assessed as part of this assessment (see the Changes in Snow, Ice, and Permafrost Across Canada chapter and the Changes in Freshwater Availability Across Canada chapter of Canada's Changing Climate Report).

Warming air temperatures contributed to a 71% decline in annual average ice cover across the Great Lakes in the period from 1973 to 2010, with the greatest declines occurring in Lake Ontario, Lake Superior and Lake Michigan (Derksen et al., 2019; Mason et al., 2016; Wang et al., 2012). Heavy ice cover occurring in 2014, 2015 and 2018 obscured any apparent trend, such that the record is marked by high inter-annual variability, but no long-term trend (*see* Figure 3.10; Derksen et al., 2019). Projections of future ice cover for Lake Ontario and Lake Erie indicate near ice-free conditions by the middle to the end of the 21st century under the RCP 8.5

scenario (Zuzek, 2020; Hewer and Gough, 2019). Seasonal ice cover is an important factor influencing wave formation, shoreline erosion, evaporation and lake levels (Zuzek, 2020; Zuzek, 2019; Lenters et al., 2013).

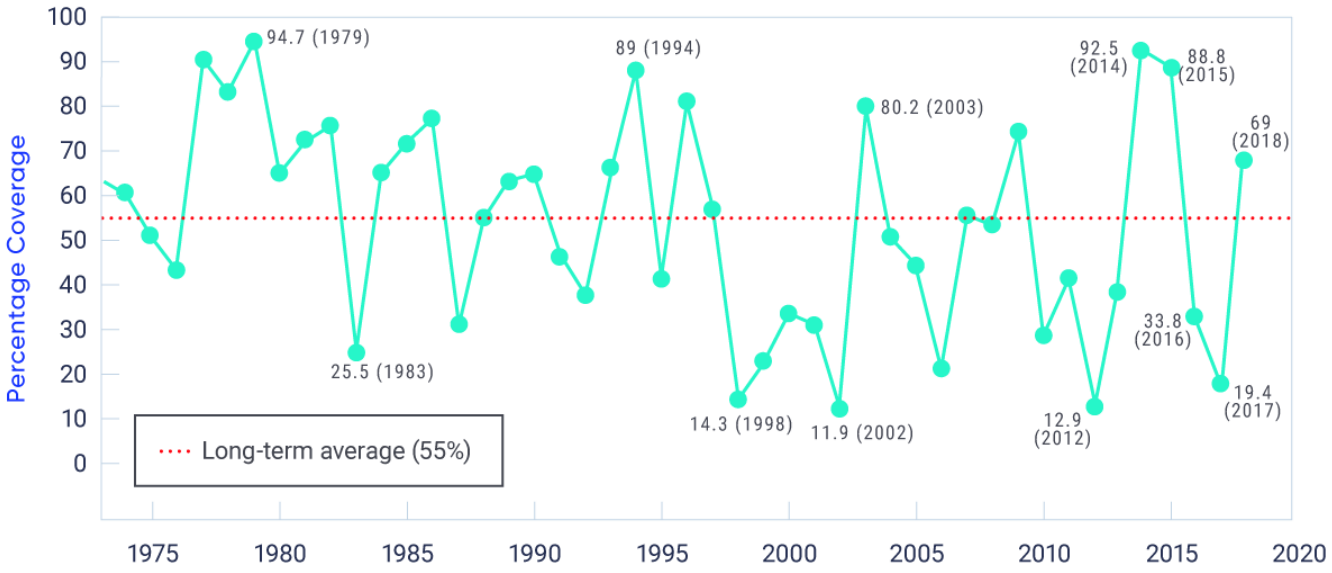

Figure 3.10: Observed Great Lakes annual maximum ice cover (%) from 1973 to 2018. The red dashed line indicates the long-term average. Source: NOAA - Great Lakes Environmental Research Laboratory, 2019.

Water levels of the Great Lakes have fluctuated over the past century, driven by natural variability, human interventions (e.g., detention diversions) and climate change. Both record low and record high levels have been experienced over the past few years. From 1998 to 2013, lower than average water levels were experienced across the lakes, with notable lows in Lake Michigan and Lake Huron during the winter of 2012/2013. These lows were followed by a rapid increase in water levels starting in 2014, largely attributed to decreased evaporation rates and increased regional precipitation (Derksen et al., 2019; Gronewold et al., 2016). In July 2019, each lake was observed to be near or above record-high water levels, with Lake Superior, Lake Erie and Lake Ontario hitting record-high values (*see* Table 3.3). The high water levels accelerated shoreline erosion and caused flooding events throughout the summer of 2019 (Seglenieks and Caldwell, 2019). It is expected that year-to-year and multi-year variability in lake levels will remain large, with potential for an increase in ranges (Bonsal et al., 2019; McDermid et al., 2015b; Gronewold et al., 2013; MacKay and Seglenieks, 2013). Extreme and unpredictable water levels are associated with significant economic costs (e.g., Shlozberg et al., 2014), such that management for both extreme high and low water levels along Ontario's shorelines will be required moving forward.

Table 3.3: Great Lakes water levels in July 2019 compared to the long-term (1918–2019) monthly average

JULY 2019 MONTHLY MEAN WATER LEVEL

Lake	Compared to Monthly Average (1918–2019)	Compared to 2018
Superior	35 cm above	21 cm above
Michigan-Huron	79 cm above	39 cm above
Erie	80 cm above	31 cm above
Ontario	79 cm above	74 cm above

Source: Adapted from Seglenieks and Caldwell, 2019.

Annual surface water temperatures of the Great Lakes have increased by between 0.02 °C and 0.06 °C per year since 1980 (United States Environmental Protection Agency and Environment and Climate Change Canada, 2021). The trend has been gradual but steady, with recent increases being driven by warming during the spring and summer months (NOAA, 2021; United States Environmental Protection Agency and Environment and Climate Change Canada, 2021). Surface water temperature is influenced by many factors, including regional air temperatures, solar radiation and ice cover conditions from the previous winter (United States Environmental Protection Agency and Environment and Climate Change Canada, 2021; Zhong et al., 2016). While water temperature projections are more complex compared to air temperature projections, models indicate that surface water temperatures across the Great Lakes will continue to warm under a changing climate (Wuebbles et al., 2019; Xiao et al., 2018; McDermid et al., 2015b).

The lengthened ice-free season and increasing surface water temperatures have led to earlier springtime and later fall lake stratification, which extends the period between turnover (Angel et al., 2018; Wuebbles et al., 2019; McDermid et al., 2015b). The physical process of turnover allows for dissolved oxygen and nutrients to be circulated and vertically mixed. As the duration between overturning events lengthens, there is less vertical mixing of dissolved oxygen and nutrients, which impacts water quality and biological function (Anderson et al., 2021; Xiao et al., 2018; McDermid et al., 2015b). During the warm winters of 2012 and 2017, surface water temperatures in parts of Lake Ontario did not fall below 4 °C (the maximum density of water), such that the overturn process was not initiated, resulting in inadequate oxygen and nutrient mixing (Wuebbles et al., 2019; Angel et al., 2018; McDermid et al., 2015b). Longer periods between stratification can be detrimental for cold-water species, as the latter are pushed closer to the surface to obtain adequate oxygen, but then challenged

by unsuitable thermal conditions (Collingsworth et al., 2017; Lynch et al., 2016; Dove-Thompson et al. 2011; Minns et al. 2011).

Warming surface water temperatures, coupled with increased nutrient and sediment runoff from land-use changes (urban development, loss or conversion of wetlands, etc.), provide optimal conditions for algae growth, increasing the likelihood and magnitude of algal bloom events (Wuebbles et al., 2019; McDermid et al., 2015b; d'Orgeville et al., 2014). Cyanotoxins within algal blooms can have significant human health impacts. Without adequate drinking water filtration systems, or through accidental exposure, these toxins can cause a variety of symptoms, such as abdominal pain, nausea, vomiting, diarrhea, sore throat and dry cough (Chorus and Bartram, 1999). Lake Erie, the shallowest of the Laurentian Great Lakes, has been particularly vulnerable to algal blooms and has experienced declining water quality in recent years as surface water temperatures and nutrient loading have increased (Wuebbles et al., 2019; d'Orgeville et al., 2014). Continued warming water and nutrient loading from agriculture operations suggest that the prevalence of algal blooms could further increase. To address this risk, the 2018 Canada-Ontario Lake Erie Action Plan identified more than 120 actions to help achieve the goal of reducing phosphorus entering Lake Erie by 40 % by 2025 (Environment and Climate Change Canada and the Ontario Ministry of the Environment and Climate Change, 2018).

The Great Lakes Basin provides habitat for more than 3,500 plant and animal species, including all three thermal guilds of fish species (cold-, cool- and warm-water species), as they co-exist in thermally stratified waters (Wuebbles et al., 2019; Milner et al., 2018a). Climate change impacts exacerbate non-climate ecological threats, such as habitat loss, pollution and invasive species resulting from human activity (Mortsch, 2016; McDermid et al., 2015b). These impacts will increase risks to fish, migratory birds and other native species that rely on healthy and resilient aquatic and coastal ecosystems (International Joint Commission Great Lakes Water Quality Board, 2017; Chu, 2015; McDermid et al., 2015b).

The physical impacts to the Great Lakes are projected to influence aquatic ecosystem function, impacting a range of processes, including nutrient cycles and uptake, phenological cues, lake productivity and turbidity and substrate conditions (Collingsworth et al., 2017; Alofs et al., 2014). Research indicates that the composition of fish communities in the Great Lakes will change as cold-water habitat becomes limited for native cold-water fish species and warm-water species expand their ranges northward (Collingsworth et al., 2017; Alofs et al., 2014; Sharma et al., 2008; 2007). There are several factors that could compound these impacts, including predator-prey mismatches, metabolism and growth rates of fish species, altered dissolved oxygen availability, and an increased incidence of disease, pathogens and invasive species (*see* Section 3.3; Collingsworth et al., 2017; Chu, 2015; McDermid et al., 2015b).

Changing lake dynamics and warming temperatures will increase the risk for the introduction of new species and the expansion of existing, invasive species (e.g., sea lamprey, zebra and quagga mussels, and phragmites), pathogens and diseases, as ranges shift northward (Wuebbles et al., 2019; Chu et al., 2015; McDermid et al., 2015b; Pagnucco et al., 2015). Coastal wetlands within the Basin have been labelled as some of the most vulnerable ecosystems to climate change in southern Ontario (*see* Section 3.3; Environment and Climate Change Canada, 2021; Chu, 2015; McDermid et al., 2015b).

3.4.2.2 Social and Economic Impacts

Climate change impacts cascade through social and economic systems within the Great Lakes Basin. They include impacts on ecosystem services (e.g., reduced soil erosion control, water purification); commercial and industrial activities (e.g., forestry, mining, shipping); agricultural productivity; tourism and recreation; infrastructure and assets, and disruptions to demand and delivery of natural resources (e.g., fisheries, energy production) (Brinker et al., 2018; Government of Ontario, 2016a; Bartolai et al., 2015; Chu, 2015; Abdel-Fattah and Krantzberg, 2014a, 2014b). Increased water level variability is projected to have significant economic implications for industry, shipping and navigation, hydroelectric generation, and agriculture and tourism (Wuebbles et al., 2019; Angel et al., 2018; Zamuda et al., 2018; Shlozberg et al., 2014).

Variable water levels and declining water quality stress and water treatment infrastructure. Some local water treatment systems in Ontario have reached capacity during extreme rainfall and flooding events, requiring the system to release untreated or inadequately treated water into the watershed (Wuebbles et al., 2019). These events have many social, health and economic implications for communities and ecosystems. Damage from extreme weather, including flood-related damage (e.g., water damage, erosion) can have physical and psychological impacts, affecting human health and well-being (Council of Canadian Academies, 2019; Hayes et al., 2019; Gough et al., 2016).

High water levels and lengthened ice-free periods in the Great Lakes Basin cause flooding and erosion that have resulted in significant property damage and economic costs (*see* Figure 3.11; IJC Great Lakes-St. Lawrence River Adaptive Management Committee, 2020; Zuzek, 2020; Moudrak et al., 2018).

Figure 3.11: Left: Eroding bluffs along Lake Erie at Wheatley Provincial Park in 2018. Right: August 27, 2019 flooding at Erie Shore Drive. Increased shoreline erosion and flood risk are attributed to changes in lake levels, ice cover and exposure to wave energy. Source: Zuzek, 2020.

Understanding of the cumulative and cascading impacts of climate change and other environmental stressors is limited (Wuebbles et al., 2019; Milner et al., 2018a). Cumulative impact assessments, which include social and economic components, are effective in examining how decisions related to land-use management and planning within the Great Lakes Basin interact with climate change (Milner et al., 2018a).

3.4.3 Resiliency and adaptation

Climate change presents new threats to the Great Lakes Basin, but opportunities for sustainable development and growth arise with effectively implemented adaptation measures. Adaptation planning and implementation have progressed across Ontario communities within the Basin over the past decade, with many different agencies, groups and partnerships participating (*see* Box 3.3). The governance of the Great Lakes is highly complex because of its transboundary, multi-jurisdictional nature. Over the years, various binational (e.g., International Joint Commission), national, provincial and state institutions and agencies have developed a number of initiatives and agreements to better protect and sustain the Great Lakes (e.g., the Great Lakes Water Quality Agreement; the Great Lakes and St. Lawrence Cities Initiative; the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement). Despite this, adaptation efforts across the Basin remain relatively piecemeal and fragmented, highlighting the recognized need for more coordinated and collaborative adaptation approaches amongst governing agencies (*see* Figure 3.12; International Joint Commission Great Lakes Water Quality Board, 2017; McDermid et al., 2015b).

Box 3.3: Mobilizing adaptation in the Great Lakes Basin

Adapting to climate change in the Great Lakes Basin requires transboundary leadership and coordination amongst all orders of government, organizations and agencies (International Joint Commission Great Lakes Water Quality Board, 2017).

The importance of adaptation is emphasized in Ontario's *Great Lakes Protection Act, 2015*, which states that the basin is "particularly vulnerable to the effects of climate change and, in the face of additional cumulative pressures such as development, population growth, loss and degradation of natural features, pollution and invasive species, three of Ontario's four Great Lakes are in decline" (Government of Ontario, 2015b). The Act calls for coordinated action, monitoring and reporting throughout the basin to identify impacts and improve provincial capacity to respond and to increase resiliency. The Act also mandates updating of Ontario's Great Lakes Strategy (Government of Ontario, 2016a) every six years to measure progress and identify knowledge gaps.

The Great Lakes and St. Lawrence Cities Initiative is an example of how local municipalities in Ontario, Quebec and several U.S. states are working together on pilot projects to advance local adaptation efforts and provide opportunities for building technical capacity (Great Lakes and St. Lawrence Cities Initiative, 2017). This binational initiative provides a platform to share climate data and adaptation resources (Great Lakes and St. Lawrence Cities Initiative, 2017).

In Ontario, Conservation Authorities (CAs) play an important role in implementing adaptation measures, and in monitoring and reporting on local conditions in their jurisdictions. With a mandate to support provincial and municipal responsibilities in resource management, CAs are key participants in provincial flood forecasting and in communicating flood warnings to local government and emergency responders. CAs also support municipalities to delineate natural hazards (e.g., floodplain mapping) as part of land-use planning. Several CAs are advancing the development, updating and implementation of natural infrastructure plans, shoreline erosion strategies, and stormwater management strategies that address climate change impacts for municipalities and others (Conservation Ontario, 2018). CAs across Ontario vary in size and capacity and, therefore, not all provide the same level of services to their municipalities and the province.

Shared Vision

- Common vision
- Clear call to immediate action
- Local and Indigenous engagement is critical
- Open declaration to be signed
- Message should be positive and inclusive

Coordinated Action

- A staffed, coordinated, binational network
- Collect, aggregate, and share science and best practices
- Framing documents to establish priorities
- Funding and capacity

Accountability

- Vulnerability assessment
- Baseline data
- Accountability will depend on the model used
- Adaptive management

Science / Info/ Knowledge

- Aggregate and share research
- Incorporate traditional ecological knowledge
- Expand the Great Lakes Water Quality Board Annex 9 to include adaptation
- Legal tools needed
- Species and habitats at risk are a key knowledge gap

Implementation Considerations

- Shared vision is fundamental to implementation
- Sector specific implementation is needed
- Tools include: recognition, certification, and incentives
- Challenges include: adapting lessons learned across borders, coordinating across sectors and nations

Figure 3.12: Key elements of a binational approach to climate change adaptation and resilience, developed by the Great Lakes Water Quality Board. Source: International Joint Commission Great Lakes Water Quality Board, 2017.

Many conservation authorities, Indigenous communities, property owners, service providers and some regional and municipal governments in Ontario have adopted adaptive management principles in responding to climate impacts in the Great Lakes Basin (Conservation Ontario, 2018; Abdel-Fattah and Krantzberg, 2014a, 2014b; Andrey et al., 2014). Adaptive management involves continuous monitoring, evaluation and improvement of management plans, strategies and programs, and is designed to enhance resiliency in an ongoing fashion (*see* Water Resources chapter of the National Issues Report; Leger and Read, 2012; Gleeson et al., 2011). Examples of implemented adaptation measures in Ontario communities include the following: flexible fish harvest regulations (e.g., slot size limits, catch limits, season lengths) for species that are vulnerable to, or that benefit from, climate change; restoring banks and shorelines to reduce erosion and flood risks; and modifying municipal zoning and building codes to account for increased coastal flooding (Myers et al., 2017; Lenarduzzi, 2016; Moghal and Peddle, 2016; Abdel-Fattah and Krantzberg, 2014a; Huff and Thomas, 2014; Lemieux et al., 2014).

Many regional and sectoral vulnerability and risk assessments have been, and are being, completed across the basin to identify priority impacts and to begin planning and implementation of adaptive solutions (Perdeaux et al., 2018). While some of this work is driven by statutory and regulatory requirements (*see* Section 3.2.3), the number of climate change adaptation plans and strategies developed by local governments will increase as more communities experience the direct impacts of the changing climate (*see* Case Story 3.3). Even with these adaptation planning efforts, examples of adaptation implementation and evaluation remain limited (National Assessment Engagement sessions, 2019).

Case Story 3.3: Local adaptation in the Great Lakes Basin

Ontario communities within the Great Lakes Basin are increasingly experiencing impacts and risks associated with climate change. Coastal flooding, shoreline erosion and declining water quality have damaged public and private infrastructure and property, raised public health and safety concerns, decreased tourism and recreational opportunities, and caused productivity losses in local industries (e.g., shipping, agriculture, fisheries) (City of Thunder Bay, 2015; McDermid et al., 2015b; City of Kingston, 2014a; City of Windsor, 2012). Several municipalities have assessed local risks and vulnerabilities associated with climate change and identified adaptive solutions to minimize the impacts (*see* Figure 3.13; International Joint Commission Great Lakes Water Quality Board, 2017).

Thunder Bay, Windsor and Kingston (all members of the Great Lakes and St. Lawrence Cities Initiative) focused much of their adaptation efforts on planning and implementing low-impact development projects, conserving and restoring natural environments, and identifying areas of high vulnerability (*see* Figure 3.13; City of Thunder Bay, 2015; City of Kingston, 2014a; City of Windsor, 2012).

Figure 3.13: Three examples of low-impact development projects. a) Memorial Avenue biofiltration low-impact development in Thunder Bay. b) Green roof low-impact development on the Lou Romano Water Reclamation Plant in Windsor. c) Alwington Avenue bioswale project in Kingston. Sources: a) City of Thunder Bay, 2015; b) Courtesy of the City of Windsor; c) Courtesy of the City of Kingston.

The City of Thunder Bay's innovative Climate Adaptation Strategy (City of Thunder Bay, 2015) and associated Web portal have increased local communication and education on climate change. The City has moved forward with implementing measures to reduce local flood risk and improve the quality of stormwater runoff through various low-impact development projects, including a biofiltration facility. The City of Windsor, an early champion of adaptation, has promoted green roofs as a means to reduce risks associated with stormwater runoff and flooding, as well as heat events (City of Windsor, 2020). Since the release of their Climate Change Adaptation Plan, green roofs have been installed throughout the city on both private and municipal buildings. A recent study ranked the City of Kingston's Climate Action Plan (City of Kingston, 2014) as the top plan in Canada for effectively addressing both greenhouse gas emissions reduction and climate change adaptation (Guyadeen et al., 2019). Kingston has also begun investing in low-impact development projects to reduce climate risks. Projects include increasing usage of permeable pavement, implementing bioswale gardens, and increasing underground stormwater storage (City if Kingston, 2014). All three municipalities recognize the importance of adaptive management in their projects and have invested in monitoring performance over time (City of Thunder Bay, 2015; City of Kingston, 2014; City of Windsor, 2012).

As municipalities in the Great Lakes Basin continue to implement and monitor adaptation measures, governing agencies have highlighted the importance of sharing lessons learned between jurisdictions and increasing coordination across sectors and all orders of government (International Joint Commission Great Lakes Water Quality Board, 2017).

3.5 Adaptation improves forest health, carbon storage and biodiversity

Climate change impacts the composition, disturbance regimes, and timing of life cycle events in Ontario's forests and forested landscapes. Changes in drought, pests, and fire and wind regimes are of particular concern given the resulting cumulative impacts.

Impacts of climate change on Ontario forests include the northward spread of pests and diseases, and damage from extreme weather events, such as drought and wind. Earlier flowering or bud burst, lengthening of the growing season and changing forest composition have all been observed in Ontario's forested landscapes in response to increased temperatures. Overall, climate change has the potential to cause both direct and indirect (through enhanced proliferation of pests and disease) damage to Ontario's forests. Developing and implementing adaptation strategies, combined with supportive forest management policies and practices, help to reduce the vulnerability of Ontario's trees to climate change, while building a more resilient forest landscape. Sustaining a resilient forested landscape also creates benefits for carbon sequestration and storage, provides ecosystem services for a variety of plants and animals, and maintains habitat connectivity to accommodate species range shifts.

3.5.1 Introduction

Ontario's landscape is 66% forested and accounts for one fifth of Canada's forest area (Government of Ontario, 2021b). The area includes four broad forested regions: the Hudson Bay Lowlands in the North subregion, the boreal forest in North and Central subregions, the Great Lakes–St. Lawrence forest in the Central and South subregions, and the deciduous forest in the South subregion (*see* Figure 3.14; Government of Ontario, 2019a).

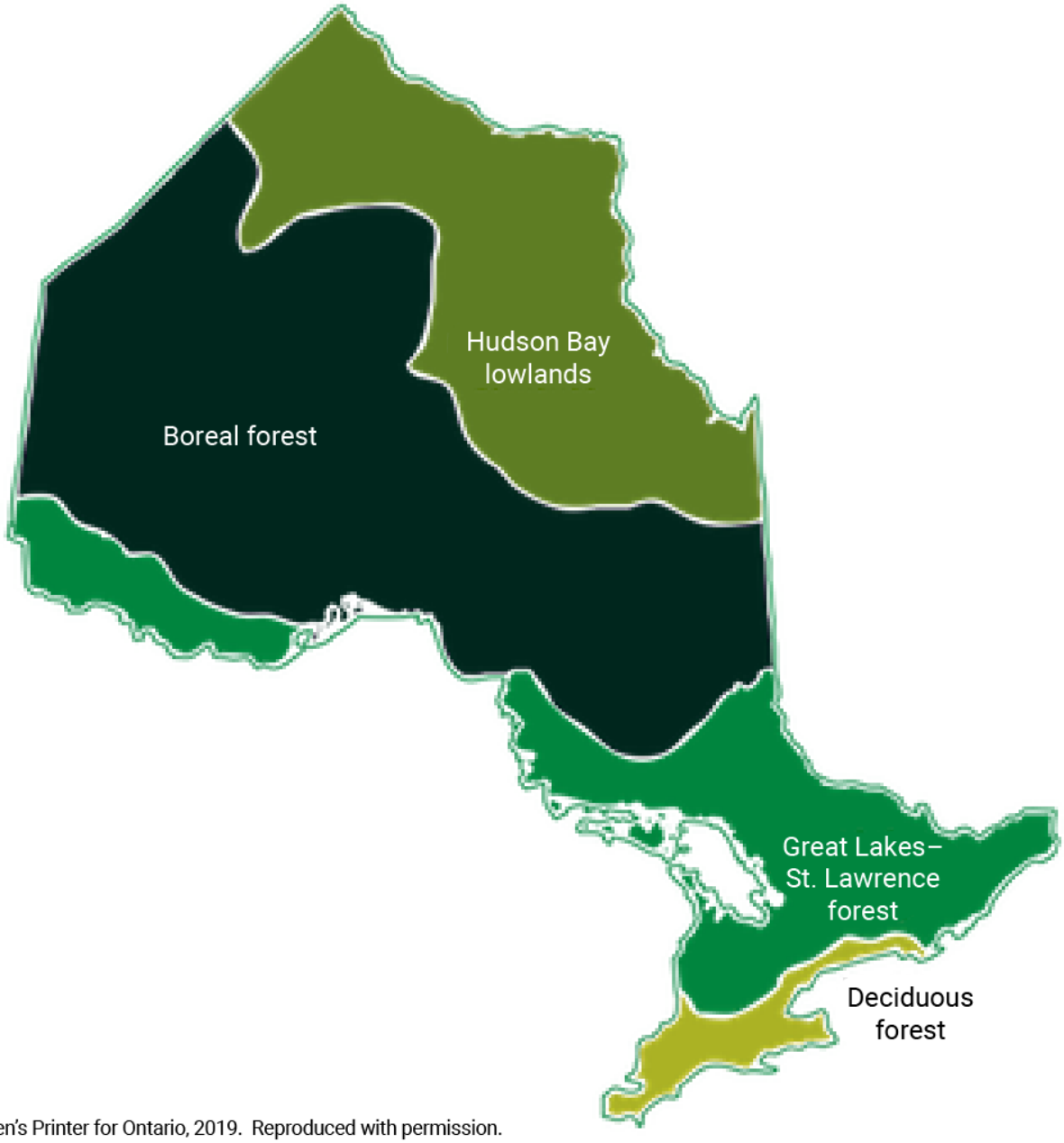

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Figure 3.14: Forest regions in Ontario. Source: Government of Ontario, 2016b.

Ontario's forests support more than 147,000 direct and indirect jobs (Government of Ontario, 2020) and generated over $18.0 billion in total revenue in 2019 (Government of Ontario, 2020). Social and cultural benefits are harder to quantify, but Ontario's forests are a source of significant cultural, aesthetic and spiritual importance to Ontarians, especially to Indigenous Peoples (Natural Resources Canada, 2018). Recreational

activities such as camping, hiking, berry picking and hunting are also supported by forests (Government of Ontario, 2020).

The unmanaged forests of the Northern subregion sequester significant amounts of carbon. Total carbon storage in this area is projected to increase by between 16.7% to 20.7% by the end of the century under all Shared Socio-economic Pathway scenarios (*see* Section 2.22 *in* Bush et al., 2022 for an explanation of these scenarios), but stands are heavily influenced by wildfire (Ter-Mikaelian et al., 2021). Carbon storage potential in managed forests in the province exceeds that of unmanaged forests, but both are heavily influenced by fire and other stressors (Ter-Mikaelian et al., 2021; Chen et al., 2018).

3.5.2 Impacts and vulnerabilities

Warmer winter temperatures have reduced the number of extreme cold days in Ontario, increasing the survival rate of forest pests, such as the emerald ash borer, forest tent caterpillar, spruce budworm and gypsy moth (Natural Resources Canada, 2019; Price et al., 2013; Candau and Fleming, 2011; Regniere et al., 2009). Warmer winters have also reduced resistance to cold and promoted earlier spring bud burst in boreal conifers, making them vulnerable to late spring frosts. For example, in northwestern Ontario in the spring of 2012, warm temperatures in March caused de-hardening, then were followed by freezing temperatures in April, resulting in a massive needle browning event, which affected more than 250,000 hectares of forest (*see* Figure 3.15; Rossi, 2015; Man et al., 2013). Recovery from browning may take several years, during which time the tree may be more susceptible to other stressors such as insects and disease (Man et al., 2013).

Figure 3.15: Aerial (left) and ground (right) views of damaged jack pine plantations near Upsala, Ontario, taken in May and June 2012. Source: Man et al., 2013.

Increasing summer temperatures accompanied by minimal increases in precipitation are projected to lead to drier conditions, more frequent drought and greater fuel loads (e.g., combustible organic matter) across the

province, driving an increase in the frequency, intensity, extent, and timing and duration of forest fires (Wotton et al., 2017; Flannigan et al., 2016; Boulanger et al., 2014; Gauthier et al., 2014). The annual area burned from wildfires could double by the 2040s and increase eightfold by 2100, under a high-emissions scenario (Podur and Wotton, 2010). By the end of the century, the area burned by large fires (*see* Figure 3.16), the number of days where fire is likely to occur, and the number of days where fire intensities exceed suppression resources are all expected to increase significantly, creating challenges for wildfire management (Wotton et al., 2017; Gauthier et al., 2015). Wildfires have cascading impacts, affecting human health and well-being, and causing economic disruptions and losses (*see* Sector Impacts and Adaptation chapter of the National Issues Report; and the Natural Hazards chapter of the Health of Canadians in a Changing Climate). Fires can affect forestry operations and timber supply, while smoke from fires can taint the taste of agricultural crops such as grapes and berries, disrupt transportation and force evacuation of residents in proximal communities, notably Indigenous communities in the north of the province (*see* Figure 3.17). Forced evacuations by air from Indigenous communities without road access, such as those that occurred in Pikangikum, Deer Lake and Poplar Hill in 2021, are especially harmful to community members. Residents of Pikangikum were scattered between communities as far away as Cornwall, at a distance of 1,600 km, for almost one month (CBC News, 2021).

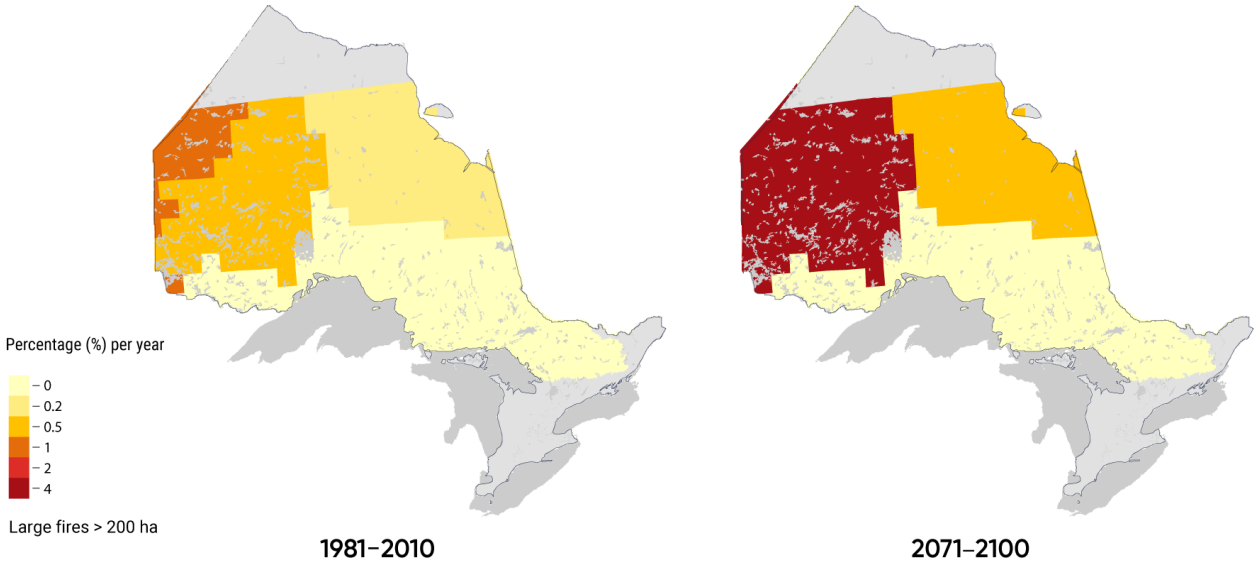


Figure 3.16: Mean annual area burned by large fires (fires larger than 200 ha) in Ontario from 1981 to 2010 (left) and projected mean annual area burned by large fires in Ontario near the end of the century (2071–2100) under a high-emissions scenario (RCP8.5) (right). Source: Boulanger et al., 2014

Figure 3.17: Glow and haze from wildfire during the evacuation of Pikangikum, July 10, 2021. Photo courtesy of Mandi Chan-Peters.

More frequent, severe and widespread outbreaks of pests and diseases are expected due to milder winter temperatures, with damage from pests increasing, particularly in the North and Central subregions of the province (Government of Ontario, 2019b; Candau et al., 2018; James et al., 2017; Pureswaran et al., 2015; Huff and Thomas, 2014; Regniere et al., 2009; Williamson et al., 2009). Damage to eastern spruce from budworm results in increased fire risk after defoliation, as breakage of dead tree tops and windthrow (trees uprooted or broken by wind) gradually build up an accumulation of "ladder fuels" that can lead to more forest fire ignitions, and allow the flames to extend higher into the forest canopy (James et al., 2017). Longer periods of moisture deficit driven by increased temperatures, lower seasonal precipitation and other factors, such as wind, will result in periods of decreased water availability, which also increase the risk of fire ignition (Candau et al., 2018; James et al., 2017).

Warming imposes constraints on the growth of several boreal species, including balsam fir and larch, which could restrict their survival by the end of the century under a high greenhouse gas emissions scenario (Yeung et al., 2019; Boulanger et al., 2017). Traits, such as sensitivity to drought-induced mortality and potential for migration failure, affect the vulnerability of tree species and populations to climate change (Aubin et al., 2018). For example, drought events in the southern part of the white spruce's range during the growing season in Ontario have exceeded the species' drought tolerance capacity, significantly increasing mortality and reducing growth rates (Sang et al., 2019). Projected temperature increases and the frequency and

severity of the growing season drought will likely result in a gradual retraction of white spruce from its current southern range edge (Weng et al., 2019).

Resilient forests provide a range of ecosystem services to society (*see* Ecosystem Services chapter of the National Issues Report). The influence of climate change on forest disturbance regimes will have negative consequences for the provision of ecosystem services and carbon storage (Thom and Seidl, 2016). However, considering climate change projections and impacts in forest management planning will help to achieve management objectives, including biodiversity, productivity and carbon storage (Ontl et al., 2020).

At longer timescales, shifting climate envelopes will result in a general northward migration of tree species in Ontario, although the pace of climate change is likely to exceed the natural ability of forests to adapt (Brecka et al., 2018; Pedlar and McKenney, 2017; Janowiak et al., 2014; Huff and Thomas, 2014; Colombo, 2008). Some populations of northern conifers respond negatively to temperature increases and are expected to decline at the southern edge of their range, decreasing their dominance in the population by up to 30% (Candau et al., 2018; Pedlar and McKenney, 2017; Janowiak et al., 2014; Thomson et al., 2010).

3.5.3 Resiliency and adaptation

Initiatives to enhance the climate resilience of forests and forested landscapes are being undertaken at regional and local scales, and involve a wide range of actions. At the provincial level, the 2017 Ontario Ministry of Natural Resources and Forestry climate adaptation strategy includes forest-specific actions such as the following: 1) reviewing tree seed and nursery stock transfer policies to ensure that they are based on the best available science; 2) exploring opportunities to improve provincial monitoring programs to take stock of climate change impacts; and 3) improving knowledge about specific tree species and habitats known to be vulnerable to climate change (Ontario Ministry of Natural Resources and Forestry, 2017b).

In 2018, the Lake Simcoe Region Conservation Authority completed a comprehensive study of the impacts of climate change on tree planting and forest management, and identified ways that local programs might adapt (Lake Simcoe Region Conservation Authority, 2018). Their list of adaptation options included the following examples: 1) increasing the genetic and structural diversity of planted stock; 2) preparing for earlier planting time frames; 3) increasing post-planting tending activities; and 4) selecting climate-appropriate tree species (Lake Simcoe Region Conservation Authority, 2018).

Climate change adaptation to increase forest resilience can also help to achieve carbon storage objectives. A range of options has been documented that can help manage climate change risks on forested landscapes (Edwards et al., 2015). Some forest management measures that support ecosystem services and overall forest health also promote carbon storage (Swanston et al., 2016). The Practitioners Menu of Adaptation Strategies and Approaches for Forest Carbon Management provides a suite of 31 approaches using seven different strategies that provide broad responses to climate change (Ontl et al., 2020).

A key challenge for forest adaptation is addressing the fact that the pace of climate change is likely to exceed the natural ability of forests to adapt (*see* Section 3.5.2). Many jurisdictions across Canada are examining the potential value of assisted migration, i.e., human interventions to deliberately relocate species to new, more climate-suitable locations (Edwards, 2015; Eskelin et al., 2011). Since 2010, six assisted migration trials

have been implemented in Ontario to compare locally sourced and more southern-sourced seeds (Forests Ontario, 2018). The movement of tree seeds beyond their current seed transfer zones requires approval from the Ontario Ministry of Natural Resources and Forestry (Ontario Ministry of Natural Resources and Forestry, 2017a). The Ministry is using SeedWhere to inform updates to the Ontario Tree Seed Transfer Policy (*see* Box 3.4; McKenney et al., 2009).

Box 3.4: SeedWhere – A climate matching tool for assisted migration

SeedWhere is a simple tool developed to assist in making seed transfer decisions for forest regeneration or other ecological restoration activities (McKenney et al., 2009; 1999). The tool identifies locations whose climate is similar to a point of interest and then uses two methods (the Gower metric and the Universal Response Function approach) to calculate climate similarity. SeedWhere can be used with any number of climate variables and was developed to incorporate climate changes. The tool can be used for both seed procurement and deployment (*see* Figure 3.18; Van Bogaert and Lorente, 2017).

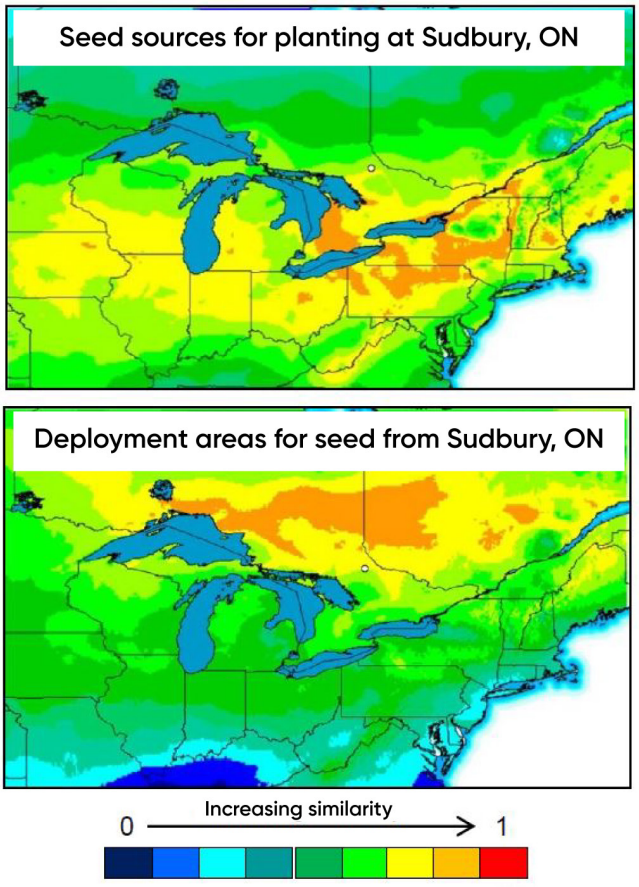


Figure 3.18: Sample output of SeedWhere, showing seed procurement and deployment for seeds in Sudbury, Ontario. Source: Van Bogaert and Lorente, 2017; "Seed sources for planting at Sudbury, ON" and "Deployment areas for seed from Sudbury, ON", Canadian Forest Service, reproduced with the permission of the Department of Natural Resources Canada.

A range of actions has been documented to help improve forest resilience in the context of changing climate (*see* Table 3.4). These adaptive strategies will improve forest health for recovery and enable a transition to new stand structure (Sang et al., 2019).

Table 3.4: Examples of adaptation options for forests and forested landscapes

THEME	ADAPTATION OPTION	SOURCE
Assisted Migration/Seed Sources	Using seeds, germplasm and other genetic material from across a greater geographic range. This may entail importing seedlings from farther away that are better adapted to current/future climate conditions.	Swanston et al., 2012
Fire	Using prescribed burning or other fuel treatments to reduce fire risk, reduce forest vulnerability to insect outbreaks and prepare forest stands for regeneration.	Swanston et al., 2012; Gauthier et al., 2014; Huff and Thomas, 2014
Forest Management Planning	Developing flexible forest management policies, plans and practices capable of responding to changes.	Gauthier et al., 2014
Habitat Connectivity	Establishing or restoring forest cover along natural features, such as rivers or property lines, which may improve species' ability to naturally adapt and migrate.	Johnston et al., 2010; Swanston et al., 2012; Gauthier et al., 2014
Harvesting	Harvesting forests that are most vulnerable to disturbance (e.g., insect outbreaks) or general decline before they reach their otherwise optimal rotation age, which allows better adapted species or populations to move in.	Gauthier et al., 2014; Huff and Thomas, 2014
Monitoring	Evaluating the adequacy of existing environmental and biological monitoring networks for tracking the impacts of climate change on forest ecosystems, identifying inadequacies and gaps in these networks, and identifying options to address them.	Gauthier et al., 2014

THEME	ADAPTATION OPTION	SOURCE
Pests/Diseases	Increasing preparedness for insect and pest management, improving pest monitoring and maintaining or improving the ability of forests to resist the spread of pests and pathogens.	Johnston et al., 2010; Huff and Thomas, 2014
Wind	Varying the shape and size of clearcuts and leaving patches or stream buffers to reduce vulnerability to potential for increased windthrow disturbance.	Gauthier et al., 2014
Species Diversity	Active management of understory regeneration to help forests make the transition to new and better adapted compositions more quickly by reducing competition from undesirable, poorly adapted or invasive species.	Swanston et al., 2012
Education/ Communication	Engaging members of the public in a dialogue on forest values and management under a changing climate, and involving them in an assessment of forest management adaptation options.	Johnston et al., 2010; Gauthier et al., 2014

Knowledge of the rate, magnitude and location of changes in forest composition and distribution remains highly uncertain (Candau et al., 2018). Adaptation in forests is further complicated by the long timelines involved, as forest management decisions made today will have effects far into the future (Lemmen et al., 2014). It is also important that adaptation objectives align with other objectives, such as biodiversity and species-at-risk. Ultimately, a comprehensive and integrated systems approach that accounts for the full range of climate impacts and the interactions between them will best improve understanding of tree vulnerability to climate change and how to support the adaptation of trees (Johnson, 2009). Collaborative initiatives, such as the Forestry Adaptation Community of Practice (*see* Box 3.5), are helpful in this regard.

Box 3.5: Forestry Adaptation Community of Practice

The Forestry Adaptation Community of Practice (FACoP) is an online platform dedicated to advancing adaptation in Canada's forestry sector. The platform allows industry members, researchers, policymakers and others involved in Canadian forestry and climate change adaptation to share information and best practices. The FACoP features recent papers/articles on climate change and forests, upcoming forestry-related events, an online library with hundreds of resources, discussion forums with member-driven topics, recordings of webinars featuring a variety of forestry and climate change experts, and more. Membership in the FACoP is free.

3.6 Climate change brings threats and opportunities to Ontario agriculture and food systems

Longer growing seasons and warmer average temperatures will benefit the agriculture sector in some parts of Ontario. However, projected reductions in summer rainfall along with more severe heatwaves, higher frequency of precipitation extremes, and increased risks from pests and diseases threaten farm operations, as well as supporting activities, such as food processing and distribution. Increased capacity and adaptation across the sector would permit the seizing of opportunities and management of risks posed by climate change.

Warmer average temperatures and longer growing seasons present opportunities for agriculture in Ontario, including the expansion of production in some regions and increased potential for specialty crops. These benefits could be offset, and potentially overwhelmed, by negative impacts associated with extreme precipitation and increased drought, resulting in increases in soil erosion, moisture stress, crop damage and livestock fatalities. Resulting risks are increased by vulnerabilities in the food processing, distribution and retail systems that are dependent on critical infrastructure. Disruptions in supply chains caused by extreme weather events cascade through the broader supply chain, often impacting vulnerable populations with pre-existing food security and access challenges. Traditional mechanisms to deal with climate impacts, such as crop insurance, may not be sustainable, highlighting the need for accelerated action on adaptation. Achieving the full potential of resilience measures requires investments in areas such as infrastructure and labour, in addition to supportive policy in areas of agriculture, water management and land use.

3.6.1 Introduction

Agri-food is a multi-faceted sector that is inextricably linked to other economic sectors and is co-dependent on infrastructure components, such as electricity, transportation and telecommunications (*see* Sector Impacts and Adaptation chapter of the National Issues Report). According to the 2016 census, Ontario's agricultural sector employed over 800,000 people (approximately 11.5% of provincial employment) and contributed $39.5 billion to the provincial economy (OMAFRA, 2016). Ontario is also Canada's top agri-food exporting province (OMAFRA, 2016).

The province's prime agricultural lands are located mostly in the South subregion and provide current and future opportunities for agriculture. Farm-level agriculture is enshrined in the social fabric of rural communities throughout this subregion. Smaller, but potentially important areas for agriculture are found in the Central subregion, particularly the Great Clay Belt (Cochrane district), Manitoulin Island, Kenora, Rainy River, Dryden and Thunder Bay districts. Further expansion of growing areas in Ontario is possible with ongoing climate change (Robinson et al., 2020; Morand et al., 2017c).

The vulnerability of agricultural systems to climate change depends largely on the characteristics of local farming systems and the specific crops that are grown. Farmers frequently implement adaptive measures and seek new technologies in order to better manage on-site weather and climate risks (Holland and Smit, 2014). These measures often involve the use of crop-specific, commodity-specific and region-specific responses and tools to improve the productivity of farming operations, including cultivar selection, adjusting the timing of cropping operations, fertilizer and pesticide application, crop rotation, tillage practices, tile drainage and irrigation optimization (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021a; Ontario Cover Crops Steering Committee, 2017; Council of Canadian Academies, 2013).

3.6.2 Impacts and vulnerabilities

Observed increases in seasonal and annual temperatures in parts of Ontario are reflected by changes in agroclimatic indices, which show increases in average growing season length, the number of growing degree days (GDDs) and rates of average evapotranspiration (Bootsma, 2012; 2011). Continued warming and increases in accumulated crop heat units (CHUs: a temperature-based index used to determine growth potential of corn) will support new crop establishment and/or range expansion into other parts of the province, including in more northerly regions where water availability and soil conditions are suitable (Qian et al., 2012). For example, in the Great Clay Belt region, where just over 18% of the 1.8 million ha of prime agricultural land is currently used in agricultural production, growing season length is projected to increase from 160 days in the 2020s to over 180 days in the 2050s under a high-emissions scenario (Robinson et al., 2020; Morand et al., 2017b). However, such benefits of climate change may be offset, or potentially overwhelmed, by a range of negative impacts, including the increased frequency and intensity of extreme weather events, which can lead to enhanced soil erosion, increased moisture stress, crop damage and an increase in livestock fatalities (Motha and Baier, 2005). The rapid rate of climate change, particularly changes in extreme temperature and precipitation events, may challenge adaptation efforts (Kulshreshtha et al., 2010; Wall et al., 2007).

A wide range of climatic and non-climatic factors influences crop growth and yield. While key factors, including geographic location, soil type, weather patterns and extreme events, are outside the control of producers, responses such as the choice of cultivars, tillage, irrigation and fertilization practices and timing of major operations provide opportunities to improve yield in any given year (Morand et al., 2017c; Brklacich and Woodrow, 2016; Holland and Smit, 2013).

A large number of studies have examined how climate risks to crops and commodities could affect future productivity. These include impacts on maize (Qian et al., 2019; He et al., 2018; Morand et al., 2017a; Zaytseva, 2016; Gaudin et al., 2015), soy (He et al., 2018; Jing et al., 2017; Zaytseva, 2016), wheat (Qian et al., 2019; He et al., 2018), canola (Qian et al., 2019; Qian et al., 2018; Wu et al., 2018), grapes (Hewer and Gough, 2019; Shaw, 2017; Holland and Smit, 2014) and maple syrup (Sugar Maple) (Brown et al., 2015; Richardson, 2015). Dynamic crop models are often used to quantify climate change impacts on crop yields (*see* Table 3.5), enabling more focused impact assessments (Luo, 2011). Differences and biases in crop models, as well as the climate scenarios and downscaling methods used, create uncertainties in projected crop yield changes (Li et al., 2018). The use of multi-model ensembles reduces biases present in individual models and is recommended in assessments (Qian et al., 2020).

Table 3.5: Estimates of annual yield change under climate change for specific crops in Ontario

CROP	ANNUAL YIELD CHANGE	CLIMATE CHANGE MODEL AND SCENARIO	TIME FRAME	REFERENCE
Maize	+9–12% +13–17%	CanRCM4 – RCP 4.5 CanRCM4 – RCP 8.5	2071–2100 2071–2100	He et al., 2018
	+41%	Multi-model ensemble – CANGRD – RCP 8.5	2041–2070	Morand et al., 2017a
Soybean	N/C N/C	CanRCM4 – RCP 4.5 CanRCM4 – RCP 8.5	2071–2100 2071–2100	He et al., 2018
Winter Wheat	-15–16% -32%	CanRCM4 – RCP 4.5 CanRCM4 – RCP 8.5	2071–2100 2071–2100	He et al., 2018
Canola	-21% -33% -27% -50%	CanRCM4 – RCP 4.5 CanRCM4 – RCP 8.5 CanRCM4 – RCP 4.5 CanRCM4 – RCP 8.5	2041–2070 2041–2070 2071–2100 2071–2100	Qian et al., 2018

Notes: CanRCM4 is the Canadian Regional Climate Model large ensemble (Environment and Climate Change Canada, 2020). RCP 4.5 is a moderate emissions scenario, and RCP 8.5 is a high-emissions scenario.

Feed and pasture forage for livestock represents 10% of Ontario's agricultural production (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016). Forage production, particularly in northern locations, is constrained by growing season length and the resulting number of harvests. Projected increases in forage yield will provide benefits to livestock farming (Payant et al., 2021; Thivierge et al., 2017) along with agricultural expansion opportunities in northern regions (Chapagain, 2017). Livestock are also negatively affected by exposure to extreme or prolonged heat (Smith and Eastwood, 2017; Bishop-Williams et al., 2015), and other weather-related factors including wildfire (Schultz and Lishman 2018), extreme cold (Tarr, 2015; Richardson, 2003) and extreme precipitation (Cheng et al., 2022; Rojas-Downing, 2017).

Climate change will lead to increased movement and establishment of invasive alien species, including pests,

disease and competing plants, which will threaten agricultural production (*see* section 7.4 of the Sector Impacts and Adaptation chapter of the National Issues Report; International Plant Protection Convention Secretariat, 2021). Increased annual temperatures allow pests to expand the northern bounds of their range, while warmer winters allow proliferation of certain pests (Baute, 2020; Taylor et al., 2018). As climate envelopes shift northward to create or expand suitable temperature conditions, the southernmost areas of Ontario stand to be the first to experience new invasive alien species, particularly in areas where their movement may be facilitated by transportation across the international border. Earlier and longer growing seasons may provide a more abundant food source for pests and, in some cases, may warrant additional application of management techniques, such as herbicides or pesticides (Baute, 2020; Taylor et al., 2018).

Aspects of food processing, distribution and retail that complement primary agricultural production and that are dependent on buildings, transportation, electricity, telecommunications and fuel supply also face exposure to climate risks. Disruptions caused by extreme weather events cascade through the broader supply system and highlight the need for adaptation at many levels and by many actors (Toronto Medical Officer of Health, 2018; Zeuli et al., 2018). In many cases, impacts to the food supply chain cascade down to vulnerable populations with pre-existing food security and access challenges (Mbow et al., 2019; C40 Cities, 2018). A systematic review of food system vulnerability was commissioned by Toronto Public Health to identify risks to the food supply chain and impacts on public health, specifically for vulnerable populations. While concluding that Toronto's food system is relatively resilient to climate change, six main vulnerabilities were identified, along with recommendations to improve climate resilience (*see* Table 3.6; Zeuli et al., 2018).

Table 3.6: Vulnerabilities and adaptation options in the food supply chain of Toronto and surrounding areas

MAIN AREA OF VULNERABILITY	POSSIBLE ADAPTATION OPTIONS
Flood risk	Business continuity planning; forms of insurance; improved awareness of the potential for flood risk
Electricity, road network and fuel infrastructure	Backup power generation capacity; planned alternate routes; disaster support hubs
The Ontario Food Terminal	Power supply redundancy
Food access in inner suburban neighbourhoods	Business continuity planning; forms of insurance; backup power generation; local community food resilience action plans; food emergency response plans
Food insecurity and the food assistance network	Addressing of underlying issues that lead to food insecurity

MAIN AREA OF VULNERABILITY	POSSIBLE ADAPTATION OPTIONS
Coordination, collaboration, planning and preparedness	Defined roles for coordination oversight; promotion of emergency planning guidance

Source: Adapted from Zeuli et al., 2018.

3.6.3 Resiliency and adaptation

Principles for building climate resilience apply to the province broadly, with several province-wide programs serving to enhance climate change education, engagement and capacity support for the agriculture sector as a whole (Morand et al., 2017c). Programs such as the Canadian Agricultural Partnership (Agriculture and Agri-Food Canada, 2021), the Canada-Ontario Environmental Farm Plan (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021b), and business risk management programs, delivered by the provincial agency Agricorp, provide access to clean technology funding, as well as mechanisms for promoting climate change adaptation and increased adoption of best management practices for soil health, water quality and other ecosystem goods and services.

Specific adaptation options are usually dependent on local-scale circumstances, and include actions such as diversifying crops, introducing different crop rotations, managing water on-site, and adjusting the timing of seeding (Qian et al., 2018; Morand et al., 2017a; Gaudin et al., 2015). Tender fruit growers use wind machines or frost fans to protect fruit against early spring frost, and hail nets and hail cannons to protect against hail storms (Ontario Apple Growers, 2018). Tender fruit, grain and oilseed growers are selecting new cultivars better suited to projected climate conditions (Hewer and Gough, 2018; He et al., 2017; Shaw, 2017; Holland and Smit, 2014). Understanding specific vulnerabilities and options to enhance climate resilience can be assisted by decision-support tools (*see* Case Story 3.4).

Case Story 3.4: Understanding and addressing agroclimatic risks and opportunities

The Ontario Climate and Agriculture Assessment Framework (Morand et al., 2017c) is a spatially explicit decision-support tool that assesses baseline and future agro-climatic risks and opportunities. It uses global climate model output to understand future crop suitability, as measured in growing degree days (GDDs), crop heat units (CHUs), potential evaporation and yield. It also gives a land suitability rating score under the influence of climate change, building on the Land Suitability Rating System developed by Agriculture and Agri-Food Canada (Agronomic Interpretations Working Group, 1995). The initial design of the OCAAF was tested and refined through application to two areas and production systems: forage-based beef production in Ontario's Great Clay Belt (looking specifically at timothy hay) and corn production in southwestern Ontario.

In both areas, climate change was found to bring opportunities to the agricultural sector through longer growing seasons, increasing growing degree days and crop heat units, and increased crop yields (*see* Table 3.7). However, climate change also presents risks that will require effective adaptation. For example, between the months of May and September in southwestern Ontario, the region is projected to see a 16% increase in potential evaporation, increasing moisture stress. Increased spring precipitation, high-intensity rainstorms and rain-on-snow events will increase risks of excess soil moisture in the Great Clay Belt, where soil drainage is already poor.

Table 3.7: Summary of changes projected by 2050 under a high-emissions scenario (RCP 8.5) for two regions of Ontario using the Ontario Climate and Agriculture Assessment Framework

	TIMOTHY HAY IN THE GREAT CLAY BELT	CORN IN SOUTHWESTERN ONTARIO
Temperature	Annual: +2.9°C Winter: +4.7°C Spring: +3.2°C Summer: +3.2°C Autumn: +3.3°C	Annual: +3.3°C Winter: +3.6°C Spring: +2.8°C Summer: +3.2°C Autumn: +3.1°C
Precipitation	Annual: +9% Winter: +19% Spring: +15% Summer: +1% Autumn: +7%	Annual: +6% Winter: +13% Spring: +13% Summer: no change Autumn: +3%
Growing season length	+50 days	+28 days
Growing Degree Days (GDD) 5* and Crop Heat Units (CHU)	GDD = +566 (40% increase)	CHU = +390 (25% increase)

	TIMOTHY HAY IN THE GREAT CLAY BELT	CORN IN SOUTHWESTERN ONTARIO
Land Suitability Rating System** scores	Shift from Class 5 (very severe limitations) to Class 3 (moderate limitations)	Shift from Class 1 (no limitations) to Class 2 (slight limitations)
Yield (kg/ha)	+2,160 (30% increase)	+3,300 (41% increase)

* GDD5 is a measure of the accumulation of days where the daily mean temperature is above 5 degrees Celsius.

** Land Suitability Rating System is a procedure for rating the suitability of land for agricultural spring-seeded small grains (and hardy oilseeds).

Source: Morand et al., 2017b.

Adaptation and policy options were developed for each region and production system, providing guidance on how to reduce climate risks and seize opportunities. For example, in southwestern Ontario, subsurface drip irrigation could help manage water at the farm level and reduce fluctuations in moisture availability. To capitalize on the improving growing conditions in the Great Clay Belt, incentives could be developed to attract new beef farmers to the area, with the goal of expanding the industry and strengthening food security in northern Ontario (Morand et al., 2017c).

The presence of mechanisms to support, enable or encourage adaptation does not necessarily result in uptake. In the absence of increased adaptation, traditional mechanisms such as agri-insurance programs may experience deficits and require additional investment by government to ensure their sustainability over time (Auditor General of Ontario, 2017). Efforts to adapt to climate change are frequently driven by economic opportunities, such as the expansion of grape production for wine, or land-use changes for the expansion of beef farming (Hewer and Gough, 2019; Morand et al., 2017b; Shaw, 2017; Beef Farmers of Ontario, 2014; Holland and Smit, 2014). Recognizing the full potential of these efforts requires investments in areas such as infrastructure and labour, as well as supportive policy in areas of land use, water and agriculture (Chapagain, 2017; Morand et al., 2017b; Barbeau et al., 2015).

3.7 Existing human health inequities will be worsened by climate change

Many non-climate factors, including income, housing quality and employment, play key roles in determining the vulnerability of communities and individuals to the health risks of climate change. Marginalized and low socio-economic populations will experience disproportionate health impacts and will have increasing difficulty in coping and adapting. Regional and local assessments of climate change vulnerability that include consideration of health equity provide a foundation for stronger and more widespread adaptation action.

Determinants of human health include many interrelated social and demographic factors, such as income level, education, literacy, social status, gender, race and culture at the scale of individuals or communities. Priority populations for adaptation are groups of people with increased risk of poor health outcomes, and those who can benefit from public health interventions. Marginalized populations are disproportionately vulnerable to climate-related changes. Local or regional climate change vulnerability and adaptation assessments that include consideration of equity can help target short- and long-term adaptation interventions. Assessments completed for many areas of the province are leading to greater efforts to monitor changing risks, provide appropriate education and outreach to the public, and implement measures to improve climate change resilience. Actions to address the underlying social determinants of health are critical for decreasing social disparities and population vulnerability, as well as advancing adaptation.

3.7.1 Introduction

Climate change increases existing threats to population health and compounds existing pressures on key factors such as water quality, food security and shelter (*see* Health of Canadians in a Changing Climate; Decent and Feltmate, 2018; Watts et al., 2018; Zeuli et al., 2018; Gough et al., 2016; Berry et al., 2014b). Vulnerable and marginalized populations, including those with existing social and health inequities, existing or underlying health issues, or economic disparities, face a disproportionally larger burden from the impacts of climate change (*see* Figure 3.19; Expert Panel on Climate Change Adaptation and Resilience Results, 2018; Berry et al., 2014b).

Legend
Risk factor
Protective factor

		Sasha, age 6	Mary, age 23	Cesar, age 42	Young, age 81
KEY HEALTH RISK		Asthma attack from pollution	Birth complications	Death from heatstroke	Heat-related heart failure
VULNERABILITY CATEGORY	SUSCEPTIBILITY	• Child • Asthma • Otherwise healthy	• Young adult • Pregnant • Healthy	• Middle age • High blood pressure • Medication increases heat sensitivity	• Older age • Heart condition • Medication increases heat sensitivity
	EXPOSURE	• Lives near sources of air pollution • Air pollution worsened by heat	• Apartment with poor insulation • Subway to work doesn't have A/C • A/C at work	• Works outside in the sun • No A/C at home	• Room on top floor • Poor A/C in nursing home
	ABILITY TO ADAPT	• Middle class • Good family support	• Poor • Lack of social support	• Undocumented immigrant • Good social support • Health insurance	• Middle class • Limited mobility
HEALTH OUTCOME		Visits emergency department for an asthma attack	Struggles to protect herself from heat but delivers a healthy baby	Develops heatstroke and nearly dies	Long hospitalization for heart failure
ADAPTATION ACTION		Real-time air quality surveillance program sends warnings to vulnerable residents when pollution levels are high	Doctor is further educated on how heat impacts clinical practice and proactively counsels on heat risk throughout pregnancy	Health officials institute new heat safety regulations to protect outdoor workers	Nursing home implements a heat emergency protocol to protect patients and invests in A/C improvements

Figure 3.19: Health vulnerabilities for different populations experiencing a heat wave. Source: Adapted from Salas et al., 2019.

Extreme weather has significant impacts on human health (Decent and Feltmate, 2018; Rajaram et al., 2016). These include direct impacts to health and safety, for example from heat events (e.g., heat stress), wildfires (e.g., loss of trees, homes, impacts on people), extreme wind (e.g., injuries from flying debris), and from heavy rainfall causing flooding (e.g., drowning) as well as indirect impacts (e.g., illness from poor water quality or exposure to mold, psychosocial trauma) (*see* Figure 3.20; Council of Canadian Academies, 2019; Gough et al., 2016; Paterson et al., 2012). The impacts of extreme weather events on mental health include incidences of post-traumatic stress disorder, depression, anxiety and grief (*see* Figure 3.21; Hayes et al., 2019; Hayes et al., 2018). The threat of climate change itself can lead to emotional distress, including "ecoanxiety," "ecoparalysis" and "solastalgia," which refers to the distress and isolation resulting from the transformation and degradation of one's home environment (Galway et al., 2019; Hayes et al., 2018; Albrecht et al., 2007).

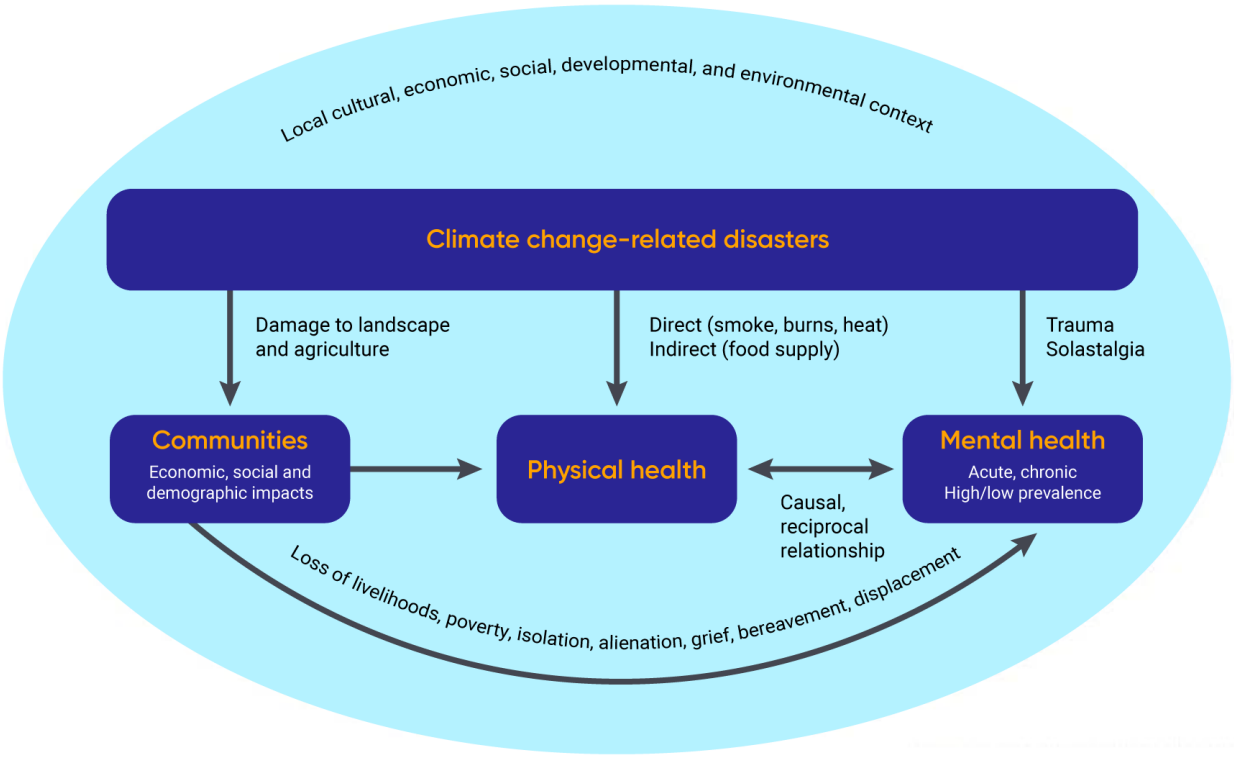


Figure 3.20: Linkages between climate change-related disasters and human health impacts. Source: Council of Canadian Academies, 2019.

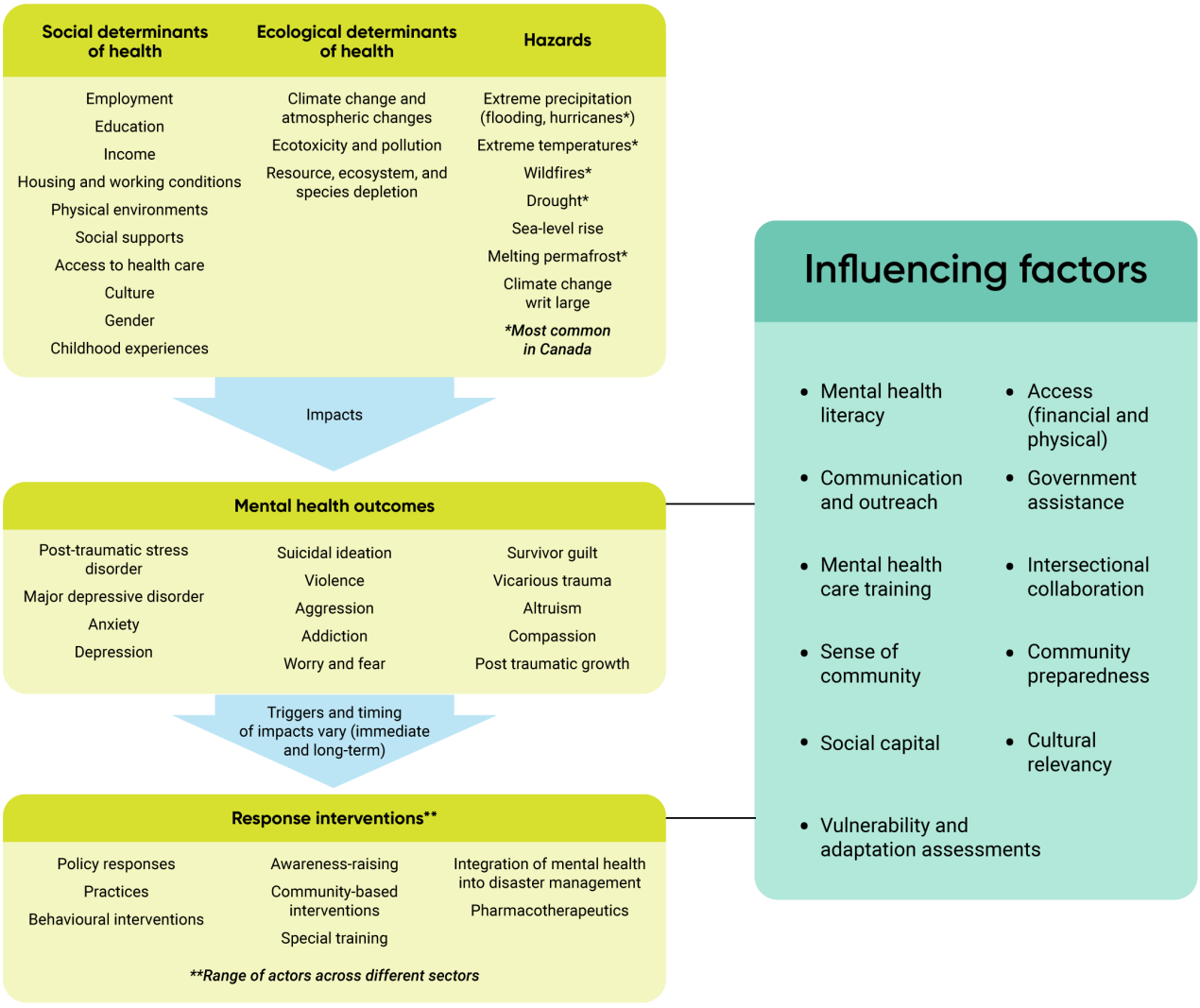


Figure 3.21: Factors influencing the psychosocial health impacts of climate change. Source: Hayes et al., 2019.

3.7.2 Impacts and vulnerabilities

Extreme heat

Extreme heat events are projected to continue to increase with climate change (Zhang et al., 2019), leading to increased risk of heat-related illness and excess deaths (Chen et al., 2016; Gough et al., 2016; Margolis, 2013). By 2100, under a high-emissions scenario, Ontario would see 38 (*28.1–44.5*) more hot days each year, while under a low-emissions scenario there would be 4.7 (*2.8–6.8*) (Zhang et al., 2019). Extreme high temperatures are associated with increased rates of hospitalization for coronary heart disease and stroke (Bai et al., 2018), diabetes (Bai et al., 2016), increased respiratory related deaths (Chen et al., 2016), and more emergency room

visits for mental and behavioural illness in Toronto (Wang et al., 2014). Ontario public health officials ranked extreme heat as their biggest concern among climate change impacts (Paterson et al., 2012). Heat warnings are triggered by regional (northern, southern and extreme southwestern) data on temperature intensity and duration, and also include humidity thresholds (Ontario Ministry of Health and Long Term Care, 2016). During a baseline period from 1971 to 2000, the frequency of a heat event (three consecutive days of maximum temperature greater than 32°C– Ontario Ministry of Labour) in all Public Health Units (PHUs) was less than one per year. By 2050, the vast majority of PHUs (28 out of 36) will experience at least one heat event annually and, by the 2080s, 33 out of 36 PHUs will see more than one extreme heat event per year (Gough et al., 2016). Windsor-Essex has noted a relationship between extreme temperature-related illnesses and increasing emergency department visits as the number of record heat days increases (Windsor-Essex County Health Unit, 2019).

Heat levels are intensified in urban centres where extensive concrete and paved surfaces produce an Urban Heat Island effect (Mohsin and Gough, 2012; Gough et al., 2001). In the absence of expanded adaptation, increased temperature extremes will lead to greater risk of heat-related illness and mortality, particularly among vulnerable populations, such as the elderly, young children, physically disabled, those living alone and those who work outdoors (Bai et al., 2018; 2016; Guo et al., 2018; McDonald et al., 2016). Projections of extreme heat in Ontario show significant increases in high temperatures over the current century (*see* Table 3.8; Canadian Centre for Climate Services, 2019).

Table 3.8: Projections of the number of days with maximum temperatures above 30°C for Thunder Bay, Sudbury, Toronto, Niagara Falls and Windsor to the middle and end of the century under moderate- (RCP 4.5) and high- (RCP 8.5) emission scenarios

NUMBER OF DAYS WITH MAXIMUM TEMPERATURE >30 °C

	HISTORICAL	ANNUAL VALUES							
	1950–2005	2050s				2080s			
		RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	MEDIAN*	MEDIAN	RANGE	MEDIAN	RANGE	MEDIAN	RANGE	MEDIAN	RANGE
Thunder Bay	2	12	1–21	12	4–27	18	8–28	35	14–53
Sudbury	4	17	4–22	22	11–37	27	10–36	47	20–62
Toronto	11	35	20–53	47	21–61	51	29–71	74	46–90
Niagara Falls	7	31	19–54	45	19–65	50	26–67	75	43–95
Windsor	18	48	33–67	61	31–82	68	43–93	94	67–105

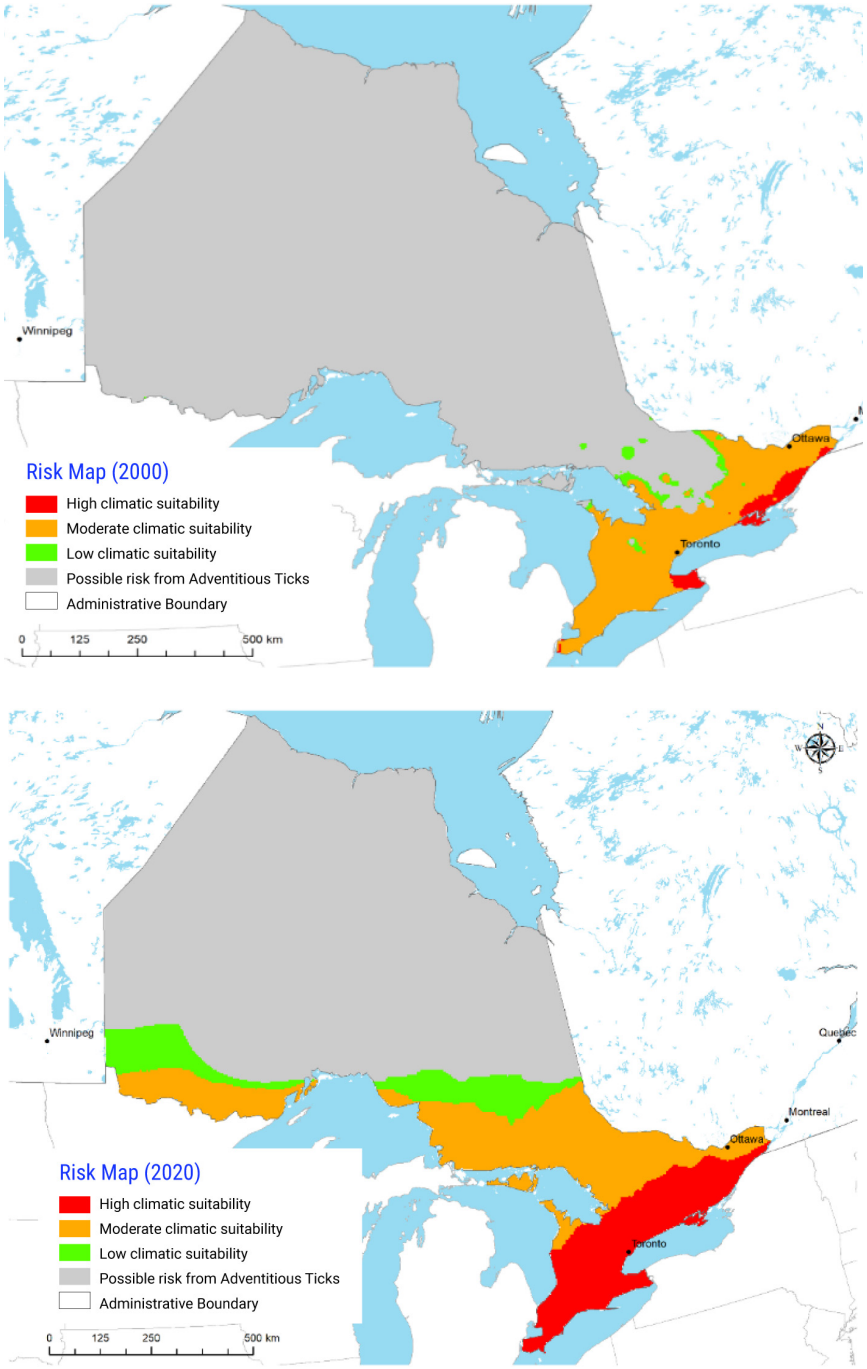
*Historical median values determined by calculating the median of annual values from 1950 to 2005.

Source: Environment and Climate Change Canada et al., 2019.

Vector-borne diseases

Warming temperatures and resulting shifts in bioclimatic envelopes have contributed to the expansion of certain disease vectors, including animals, ticks and insects (Gough et al., 2016; Berry et al., 2014b). Mosquito-borne diseases have increased by approximately 10% in Canada in the last two decades (Ludwig et al., 2019). Some of these diseases, including the Chikungunya virus, which has historically been limited to travel-related cases, could expand to parts of southern Ontario as temperatures increase and conditions become more favourable for transmission (Ng et al., 2017). The observed northward expansion of the blacklegged tick in Ontario, which is responsible for transmitting Lyme disease, is in part due to temperature increases (Cheng et al., 2017; Clow et al., 2017; Werden et al., 2014). The number of confirmed and probable

Lyme disease cases observed in Ontario PHUs was three times higher in 2017 than the average from 2012 to 2016, and twice as high in 2018 (Ontario Agency for Health Protection and Promotion, 2019; Nelder et al., 2018). Northward and westward expansion of the distribution of blacklegged ticks and the associated risk of Lyme disease are projected to continue throughout this century in response to changing climate (*see* Figure 3.22; Gasmi, 2019; Sagurova et al., 2019).



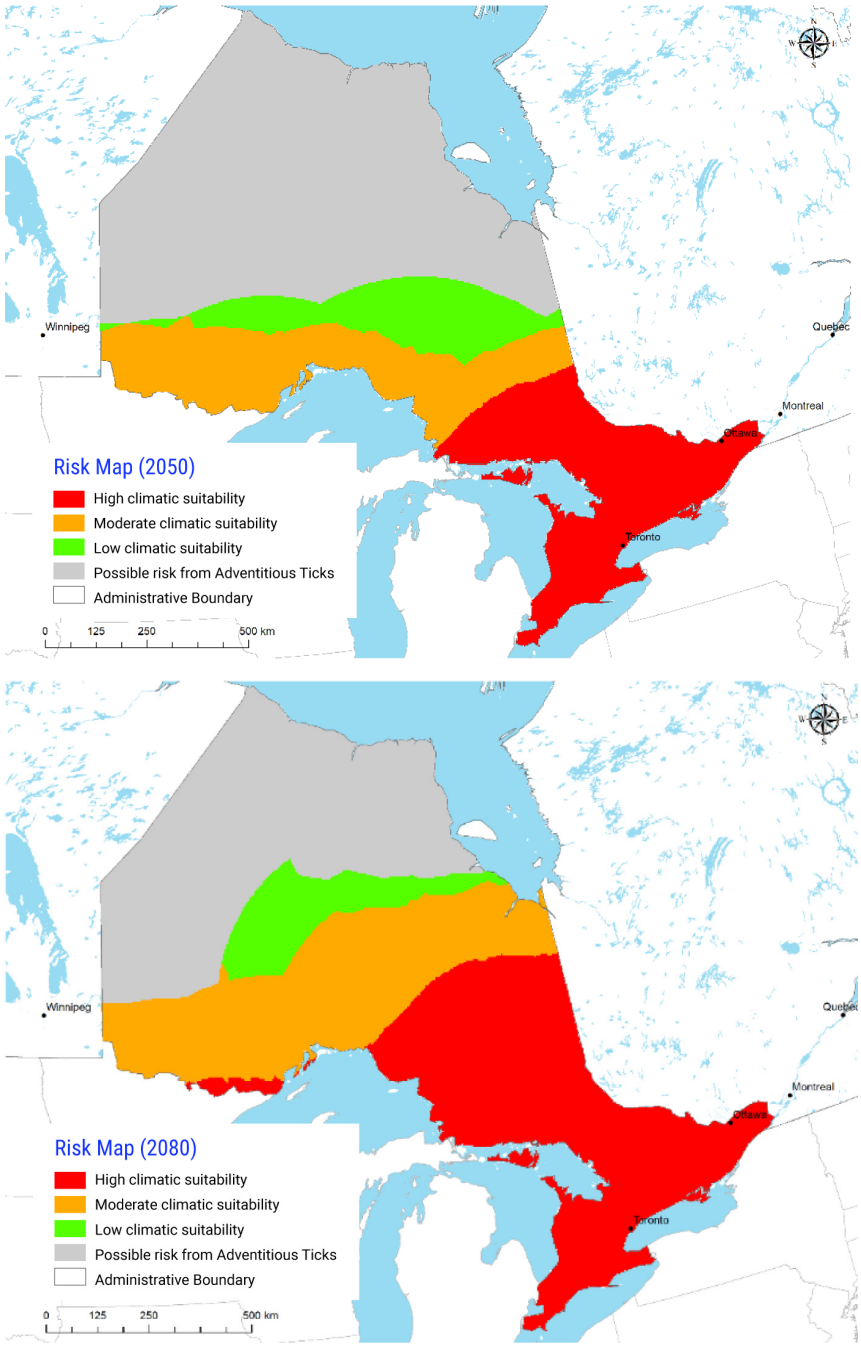


Figure 3.22: Risk maps for populations of the blacklegged tick (Ixodes scapularis) vector of Lyme disease historically (1971–2000) and under future emissions scenarios (2020s, 2050s and 2080s). The climate data was derived using the Canadian Regional Climate Model version 4.2.3 and was forced by a high (A2) emissions scenario. Red = areas of high risk, orange = areas of medium risk, green = areas of low risk and grey = areas of no risk of tick populations. Within "no risk" areas, there is a low, but real risk of acquiring Lyme disease due to adventitious ticks dispersed by migratory birds. Source: Courtesy of Nick Ogden.

Health impacts in the North subregion

Indigenous communities in Ontario's North subregion have experienced flooding on several occasions. Whether driven by rapid snow melt, rain on frozen ground or ice jams in the large rivers, flooding in the spring season can bring significant anxiety. Extreme weather and flooding increase the risk of water contamination, water-borne illness and vector-borne disease, and can disrupt critical health care services in hospitals and clinics, as well as in other institutions (Giordano et al., 2017; Clarke, 2009; Brunkard et al., 2008; Cretikos et al., 2007). Anxiety and other mental health conditions are also triggered through evacuations related to wildfire, as well as flooding, and when critical transportation and energy infrastructure is disrupted, highlighting how impacts cascade through an interdependent system (Cunsolo 2018; 2014). These conditions can reverberate over time in the form of post-traumatic stress disorder, emotional fatigue, substance misuse and a lost sense of place (Bourque and Cunsolo Willox, 2014).

Food insecurity is also causing health impacts. Moose, a major source of wild food for many central and northern Ontario First Nations, is in decline in much of the region (Arsenault et al., 2020). Climate change, through later frost onset and earlier spring warming, is increasing exposure to fatal parasites transferred from white-tailed deer (Priadka et al., 2022). Deer are expanding northward in response to shorter winters and decreased snow depth allowing easier movement and access to browse (the leaves, twigs, and buds that deer eat) (Dawe and Boutin, 2016). Alteration of habitat by human and climate influences that reduces the density of the forest canopy is amplifying the impacts on moose by allowing easier access for predators and increasing the accumulation of snow on the ground, making it more difficult for younger animals to negotiate the snow and find browse (Priadka et al., 2022). In Biigtigong Nishnaabeg (Pic River) First Nation, on the north shore of Lake Superior, residents are adapting to the northward shift in the moose population by using a mobile app to pass on information to others about moose sightings, as well as signs of visible parasitic diseases on moose in their Traditional Territory (Popp et al., 2018).

People in thirty-one First Nation communities in the North subregion rely on winter roads to travel south in winter (*see* Section 3.2.2) for medical services from specialists and in hospitals, as well as to obtain food and other essential supplies (Ontario Ministry of Energy, Northern Development and Mines, 2019). Winter roads transect the traditional territories of most communities in the Nishnawbe Aski Nation and many in Grand Council Treaty #3. Personal snowmobile travel on frozen lakes and rivers supports hunting and fishing, which are not only integral components of subsistence living, but are also fundamental to Indigenous culture (Cunsolo Willox et al., 2014). However, safety is increasingly compromised by thin ice during warmer winter weather, notably in sections that span large water bodies (Hori et al., 2018a; 2018b). Unreliable access for heavy transport vehicles limits commercial food deliveries, making healthier food options such as fresh fruit and vegetables either not available or too expensive. In response, many have begun to develop family and community gardens, taking advantage of a lengthening growing season, and are also building greenhouses (Sioux Lookout First Nations Health Authority, 2019).

3.7.3 Resiliency and adaptation

Public Health Units (PHUs) across the province are, to varying extents, already assessing and managing the impacts of climate change on human health (Paterson et al., 2012). Addressing public health risks from

climate change and extreme weather is mandated through the Ontario Public Health Standards, which references climate change in sections related to population health assessment, healthy environments, and prevention and control of infectious and communicable diseases (Ontario Ministry of Health and Long-Term Care, 2018b; Paterson et al., 2012). Some PHUs (e.g., Peel Region, London Middlesex, Simcoe Muskoka and Grey-Bruce) have undergone comprehensive studies and have published climate change vulnerability assessments and adaptation plans (Grey-Bruce Health Unit, 2017; Levison et al., 2017; Berry et al., 2014a; Region of Peel, 2012). These analyses detail local risks, highlight improvements to monitoring and implementation of adaptation measures, and consider how climate change goals can be aligned with health equity (Buse, 2018).

The Ontario Climate Change and Health Toolkit contains guidelines (Ebi et al., 2016) and a workbook (Paterson et al., 2016) for conducting climate change and health vulnerability and adaptation assessments, as well as a climate modelling study (Gough et al., 2016) that forecasts key health impacts for PHUs. A complementary National Climate Change and Health Workbook and Knowledge Primer to guide adaptation planning for health professionals is currently in development.

Early warning systems and associated response measures are a key feature of health adaptation initiatives in Ontario. The provincial harmonized heat warning, established in 2016, provides a consistent approach and methodology for monitoring weather forecasts, identifying signals of a potential localized heat event and notifying PHUs that, in turn, can provide targeted, heat-related warnings and messages (Ontario Ministry of Health and Long-Term Care, 2016). The standardized messaging provided by these alert systems include details about the event itself (onset, intensity, duration), as well as response messaging, for example about who is at risk and potential symptoms of heat stress or stroke (Ontario Ministry of Health and Long-Term Care, 2018b). PHUs can escalate heat warnings and, alongside emergency management and municipal stakeholders, implement additional measures to protect vulnerable populations from extreme heat. Implementation of these heat alert systems in Hamilton, Toronto, Sudbury, Kingston and Windsor provides valuable lessons learned (*see* Case Story 3.5; Guilbault et al., 2016).

Case Story 3.5: Local actions to address extreme heat

A series of 20 case studies examined how cities across Canada are adapting to extreme heat (Guilbault et al., 2016). The analysis identified core elements of heat alert and response systems designed to reduce the risk of illness and fatality during extremely hot days (*see* Figure 3.23). It also highlighted the following seven lessons learned:

- **Many communities are taking action now.** Actions include Heat Alert and Response Systems, as well as preventative actions like incentivizing urban greening through green or cool roofs that reflect or absorb sun rays, and tree planting programs to increase the urban tree canopy and reduce heat island effects (e.g., Toronto Public Health).
- **A culture of prevention is the trigger for action.** While decision-makers are often motivated to implement resilience measures after a major event such as a flood or wildfire hits a community,

some communities have taken action to prepare for extreme heat before fatalities occur after witnessing impacts outside of their community.

- **There is great value in existing networks and partnerships.** Public health officials can work alongside existing networks and partnerships, including with city officials, emergency services, school boards, seniors' homes and community members, to assess risks, implement preventative measures and develop robust planning responses. In Ontario, many PHUs, including the Northwestern, Middlesex-London, Peel, and Simcoe-Muskoka health units, have leveraged relationships with their communities and other partners to conduct vulnerability assessments and develop adaptation plans.
- **Evaluation and continuous innovation are essential.** There are opportunities to assess the efficacy of existing plans and systems, and to identify innovations tailored to the individual community.
- **Focus preparedness on the most vulnerable.** Programs need to focus on assessing vulnerability and ensuring that strategies are aligned with high-risk populations, like seniors who do not have access to air conditioning.
- **Invest in prevention to reduce the risk of loss.** There are opportunities to invest in multifaceted solutions that extend past traditional public health interventions, like urban planning policies.
- **National and provincial leadership supports local preparedness.** Support includes funding, education and a community of practice where lessons learned can be shared across jurisdictions (e.g,. Health Canada's HealthADAPT program).

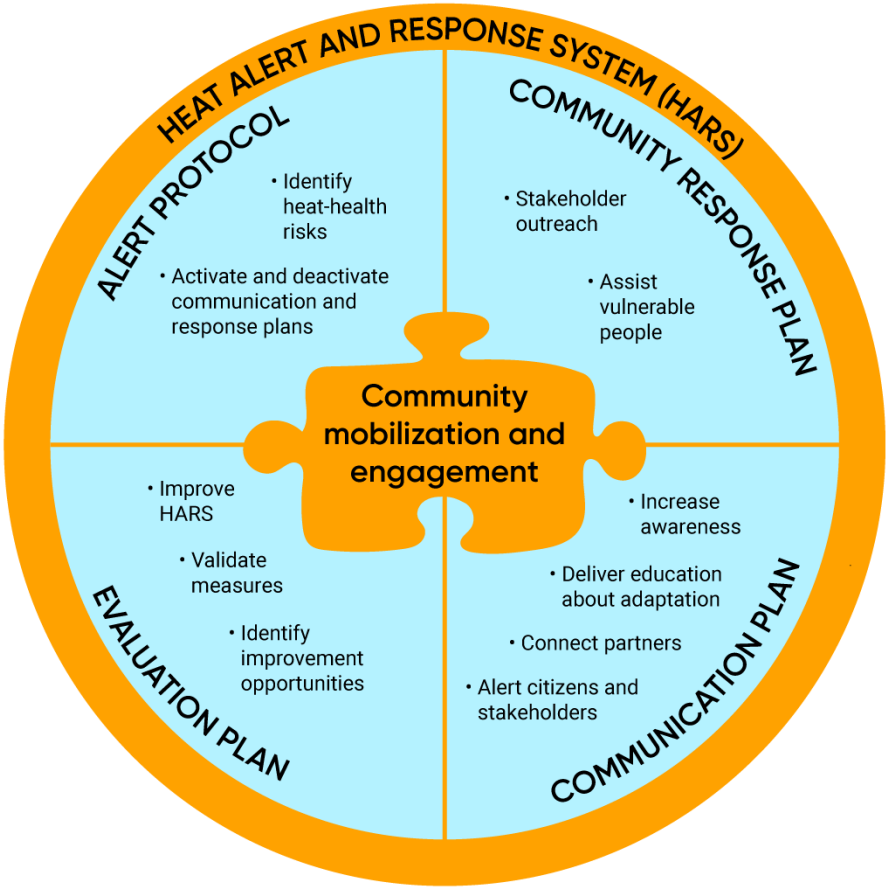


Figure 3.23: Core elements of heat alert and response systems. Source: Guilbault et al., 2016, published by the Institute for Catastrophic Loss Reduction.

Warning systems are also in place to identify mosquito-borne disease outbreaks like West Nile virus. Such systems can be adapted and improved to incorporate weather forecasting to supplement conventional public health surveillance techniques, similar to those piloted by the Peel Region Public Health Unit (Ogden et al., 2019; Wang et al. 2011).

The strong linkages between a population's social and economic circumstances and its health (Keon and Pépin, 2009) are recognized as key factors in determining vulnerability to climate health impacts (City of Toronto, 2016; Toronto Public Health, 2015; Berry et al., 2014b; Toronto Public Health, 2008). Programs that target the underlying causes of inequity will lessen climate risks and improve overall quality of life (Buse, 2018). Institutional capacity to protect vulnerable populations through the provision of emergency services, access to hospitals, cooling and warming centres, and other actions contributes significantly to reducing health-related impacts of climate change. The presence of green spaces is also associated with improved

health outcomes, including improved air quality and provision of shade for cooling (Kingsley and EcoHealth Ontario, 2019; Mitchell and Popham, 2008).

3.8 Progress on adaptation remains limited in Ontario

Levels of climate change adaptation planning and implementation vary considerably across Ontario, with the primary focus still placed on the assessment of risk and vulnerability. Although there are examples of implementation, there is little evidence of adaptation being mainstreamed into decision making broadly. Systems for monitoring and evaluating adaptation action and effectiveness remain inadequate in most jurisdictions.

Climate change assessments completed across the province paint a clear picture of the risks to society as a whole. Data, research, knowledge and information products on climate change impacts have improved awareness about the need to adapt in conjunction with significant efforts to reduce greenhouse gas emissions. While various tools, frameworks and supporting mechanisms have been developed and applied to support the adaptation process, adaptation action in Ontario remains primarily focused on defining climate change risks, with relatively few examples of implementation. Regions and cities, public health units, conservation authorities and some Indigenous communities are leading in addressing climate change within their jurisdictions. Scaled-up adaptation implementation, as well as concrete and systematic ways to measure and report on the effectiveness of adaptation actions that have been implemented are important.

3.8.1 Introduction

Implementation of adaptive measures and the mainstreaming of adaptation into existing decision-making processes initially require efforts to methodically build knowledge and assess risks (*see* Figure 3.24; Ministry of Environment and Climate Change Strategy, 2019; ICLEI, 2016; Canadian Council of Ministers of the Environment, 2015; Douglas et al., 2011; Gleeson et al., 2011; Black et al., 2010). The core elements of a risk-based approach for climate resilience are consistent with international standards such as ISO 31000 (2018), ISO 14090 (2019) and ISO 14091 (2019). These processes, supported by appropriate expertise and resources, provide a backdrop for planning and implementation to occur (*see* Case story 3.6).

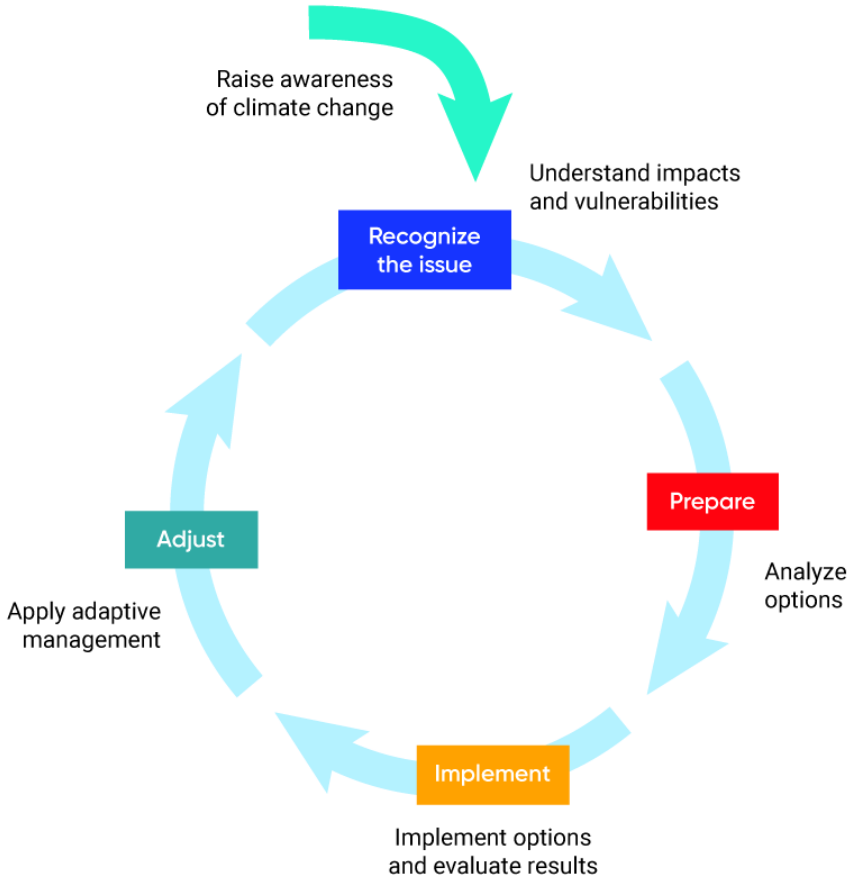


Figure 3.24: The adaptation cycle as presented in the Blackfeet Climate Change Adaptation Plan. Source: Wagner et al., 2018.

Case Story 3.6: Climate change adaptation by the Georgina Island First Nation

Georgina Island First Nation, located along the east shore of Lake Simcoe, is dealing with a number of climate change impacts that have disrupted the community. Warmer winters have negatively affected the ability to travel from the island to the mainland via the ice road, and more frequent strong winds have damaged houses and other infrastructure. In response, the First Nation embarked on a community-based project in 2012 that collected and used Indigenous Knowledge as the foundation for climate change adaptation planning and for reducing greenhouse gas emissions. Risks and vulnerabilities associated with current and future climate change were identified, and recommendations were developed using a multi-step assessment framework.

An advisory committee comprised of Elders, youth and community members was established to provide project oversight and guidance. The committee met several times over the course of the project to learn about progress, provide advice on community priorities and review project results. A community adaptation liaison, hired from within the First Nation, worked closely with the community and partners throughout the project. Through one-on-one interviews with the liaison, community Elders, adults and youth shared their knowledge about changes in weather and climate, and how these changes have impacted their community. Bingo information sessions, interactive workshops and day-to-day interactions with community members provided opportunities to learn and provide feedback about the project and results (*see* Figure 3.25). Keeping the community informed and engaged was a fundamental part of the adaptation planning process.

Figure 3.25: Interactive risk assessment workshop with Georgina Island First Nation community members.
Source: Photo courtesy of Kerry Ann Charles.

The project developed 67 recommendations, all of which were vetted by the community, and a plan to implement them. One of the first recommendations to be implemented was the restoration of a creek that at one time flowed for nine months of the year, but had dried up in recent years. Because this creek was seen as a key location to alleviate potential flooding caused by intense precipitation, the community worked with property owners, a team of experts and individual community members to restore the creek. Since its restoration, the previous flora and fauna have reappeared and function to moderate the high volumes of water associated with heavy rainfall. Monitoring of the site by the Waabgon Gaming students, the First Nation Environment Department and project partners is ongoing. As monitoring proceeds, adjustments will be made to ensure that the creek remains functional and can be enjoyed by future generations.

Following the success of the project in their own community, Georgina Island First Nation reached out to neighbours within their Tribal Council and, using the same model, the community adaptation liaison and project partners have helped four other First Nation communities to start the climate change adaptation planning process (Charles, K.-A. 2019).

3.8.2 Adaptation planning

Adaptation planning in Ontario varies in scale and scope. Multi-themed assessments (e.g., Lalonde et al., 2012; Douglas et al., 2011) identify risks across broad landscapes, while more technical and in-depth analyses (e.g., Tu et al., 2017), often employing geographic information systems and climate change information, delineate risks at finer scales.

The institutional arrangement of Conservation Authorities (CAs) in Ontario has proven successful at advancing adaptation planning at watershed scales, particularly as it relates to flood risk. As watershed and ecological stewards with jurisdictions stretching across many municipal boundaries, CAs participate in municipal and regional climate change initiatives in addition to having their own climate change plans (e.g., Lake Simcoe Region Conservation Authority). CAs have undertaken research to advance the climate change knowledge base, established best practices for managing climate change risk, and developed tools to assist adaptation decision making (e.g., the Risk and Return on Investment Tool (Credit Valley Conservation, 2020) and the Source Water Protection Tool (Milner et al., 2018b)). CAs are also key partners in the development and implementation of municipal or regional adaptation plans, including those in Kingston (City of Kingston, 2014), Thunder Bay (City of Thunder Bay, 2015), Windsor (City of Windsor, 2020; 2012) and Durham Region (Durham Region, 2016). All of these plans reflect the collective input of many partners contributing expertise or experience to mobilize adaptation across multiple themes and sectors.

3.8.3 Implementation, monitoring and evaluation

Despite significant progress with respect to adaptation planning, the level of implementation of adaptation actions in Ontario remains low. Climate resilience planning has not kept pace with the rate of climate change, and the adaptation deficit in Ontario (Environmental Commissioner of Ontario, 2018a) continues to grow.

Many provincial government policies have the potential to support adaptation and climate resilience. The Provincial Policy Statement (Ontario Ministry of Municipal Affairs and Housing, 2020), environmental assessment guidelines (Ontario Ministry of Environment, Conservation and Parks, 2014), asset management planning guidelines (Ontario Ministry of Infrastructure and Ministry of Transportation, 2012), the Northern Ontario Growth Plan (Ontario Ministry of Infrastructure and Ministry of Northern Development, Mines and Forestry, 2011) and other policy instruments signal recognition of climate change impacts and the need for adaptation.

Barriers that impede progress on the planning, implementation and evaluation of adaptation in Ontario include financial constraints, lack of expertise and access to data, limited political will, support and mandate for action, and uncertainty associated with roles and responsibilities (*see* Box 3.6; Abdel-Fattah and Krantzberg, 2014a; Gregg et al., 2011). Addressing these barriers would help mainstream adaptation into policy and planning processes.

Box 3.6: Reported barriers to adaptation action

A state-of-play report on climate change adaptation and infrastructure (AMEC Foster Wheeler and Credit Valley Conservation, 2017) and engagement sessions conducted in Ontario in 2019 to support development of this chapter highlighted several perceived barriers to adaptation action. These include the following:

- Inconsistent guidance or lack of guidance and direction from the provincial and federal levels related to climate change;
- Need for municipal direction on how to define risk tolerance, particularly within existing urban areas;
- Need for municipal direction on how to set design goals for infrastructure to meet the needs of future climate within its lifespan;
- Lack of defined roles and responsibilities for water infrastructure, which creates confusion and a lack of integrated adaptation strategies;
- Insufficient collaboration among departments;
- Lack of engineering tools to support optimization of adaptation measures or financial tools to make an effective business case for adaptation action;
- Insufficient funding to implement adaptation initiatives; and
- Lack of streamlined climate change data and resources to accelerate implementation.

The inherent complexity and diversity of climate change impacts, the multiple scales and cross-cutting nature of some adaptation actions, and other factors make tracking the success of adaptation challenging (Expert Panel on Climate Change Adaptation and Resilience Results, 2018). Indicators for province-wide monitoring and evaluation of adaptation implementation would help define pockets of inaction, create examples of success and inspire further action.

While progress has been made on adaptation planning in Ontario, action is fragmented and has not been conducted in a systematic way. This is not necessarily a negative, as a variety of approaches are required to determine best practices. Planning to date has primarily been undertaken in larger regions or cities where there is greater capacity and resources, disadvantaging smaller communities. Stronger coordination and governance among those implementing adaptation planning processes can improve information sharing and expedite climate resilience.

3.9 Moving forward

Assessing progress on adaptation in Ontario remains challenging. Registries or databases of climate change risks in various sectors and regions, such as those that exist elsewhere (e.g., BC Ministry of Environment and Climate Change Strategy, 2019; UK Government, 2017), establish a baseline for measuring progress and help to prioritize adaptation actions. In Ontario, province-wide inventories of climate change impacts, risks and adaptation actions are not yet in place. As adaptation implementation increases, registries would help document changing climate risks and provide examples of sector- or region-appropriate adaptation actions.

In addition to those major gaps, a number of key, and in some cases new, issues would benefit from additional research. These include governance, data availability, reducing uncertainties, risk transfer, cultural impacts and funding mechanisms.

3.9.1 Governance

Governance of climate change issues is complex due to the range of authorities, including national, provincial and local governments, Indigenous communities, the private sector, civil society and other actors who work in this space. Coordination among all these parties on aspects of climate change adaptation can be challenging. A centralized information-sharing platform that includes climate science, climate change data, impacts, risk levels and adaptation would help facilitate access to information and increase coordination between actors, while also defining research opportunities related to cumulative impacts and interdependencies within the region (Angel et al., 2018; Milner et al., 2018a).

The issue is compounded in the Great Lakes Basin by the international dimension involving two countries and multiple provinces and states. Within the Basin, and under mandate from the Government of Canada and the United States Government, the International Joint Commission has engaged with local, state and provincial governments to coordinate action on climate change (International Joint Commission Water Quality Board, 2019; 2017) and will seek to advance elements of a binational climate change adaptation and resilience strategy in 2022 (International Joint Commission, 2020).

3.9.2 Access, format and interpretation of climate change data

While climate data has become more accessible over the last few years, particularly with the launch of the Ontario Climate Data Portal (Zhu et al., 2018) and the Canadian Centre for Climate Service's Climate Data platform (Environment and Climate Change Canada et al., 2019), actionable climate information continues to be identified as a barrier for communities and others who undertake assessment or adaptation planning processes. Even when practitioners have access to local climate information, there is often a lack of understanding of the data, including which datasets are most useful for specific decisions (Milner et al., 2018a). The utility of climate datasets could be improved by including interpretation summaries that highlight general data trends (Milner et al., 2018a). The development of climate science communication pathways (e.g., data-sharing platforms and forums) would allow for information to be effectively communicated among

various sectors and stakeholders, and would contribute to improving the use of climate science information for informing adaptation decisions (Milner et al., 2018a; International Joint Commission Great Lakes Water Quality Board, 2017).

3.9.3 Uncertainty of climate change impacts on lake water balance

Climate change affects the quantity of water in lakes and rivers, primarily through changes in temperature, precipitation and evaporation. The balance of these influences is difficult to assess, and this becomes even more challenging in the context of climate change. In the case of the Great Lakes, there are divergent views on future water-level trends (Bonsal et al., 2019; GLAM Committee, 2018; Angel and Kunkel, 2010). Recent experience with both high lake levels (Lake Ontario and Lake Erie in 2017 and 2019) and low lake levels (Lake Huron and Lake Michigan in 2013) indicate that extremes in water levels can vary considerably within relatively short periods (Gronewold and Rood, 2019), which reveals the need for resilience measures that can accommodate both high water and low water scenarios over time.

3.9.4 Regional risk transfer to the Great Lakes Basin stemming from climate change

Climate change impacts elsewhere in North America, and elsewhere in the world, could stimulate migration to seemingly water-abundant areas like the Great Lakes Basin (American Society of Adaptation Professionals, 2021; Great Lakes Now, 2021). Research concerning transboundary climate change impacts and the migration of people into the area remains limited. Research into the impacts of climate change on other domestic and international regions, and into subsequent effects on the Great Lakes Basin, is warranted.

3.9.5 Climate change impacts on Indigenous culture and mental health

Long-term climate change can have magnified impacts on Indigenous culture, particularly in northern Indigenous communities. As climate change affects all aspects of the biosphere, cultural aspects that are intimately tied to the environment are also affected. Knowledge about the impacts of climate change on the mental health of Indigenous Peoples in Canada (Cunsolo and Ellis, 2018) continues to evolve, but with few examples coming from Ontario. Short-term displacements, like community evacuation in the event of a flood or wildfire, can compound levels of stress among displaced people, further increasing vulnerability within communities. Given the significant social and economic challenges that exist within northern Indigenous communities, programs to monitor and address impacts to mental health are important.

3.9.6 Innovative financial mechanisms

The impacts of extreme weather events, combined with infrastructure and adaptation deficits, have led to increases in insured and uninsured losses in Ontario. Large asset holders, including investment firms, property holding companies and pension funds, have yet to mobilize on climate change adaptation in a significant way. These sectors are increasingly reporting on climate risk for their own portfolios, but also have a role to play in mobilizing or unlocking financing for adaptation investment (*see* Climate Disclosure, Litigation and Finance chapter of the National Issues Report). There is a need to further mobilize the investment community and researchers to use innovative financial mechanisms that promote adaptation action and can assist in disaster recovery.

3.10 Conclusion

The signs of climate change in Ontario are clear, both from the observations of Indigenous peoples and other citizens as well as from records of temperature, precipitation and other climate variables. Despite strong understanding of ongoing and projected future climate change impacts, proactive, evidence-based adaptation remains limited in virtually all sectors and regions of the province. Even where adaptation planning is occurring, the lack of broader coordination results in missed opportunities for expanding this work.

Rapid and widespread population growth and urbanization are expected in the Greater Toronto Area and the Greater Hamilton Area, as well as in other pockets of the province; these will further fragment and stress ecological habitat. Healthy and intact ecosystems remain fundamental to having healthy communities and addressing climate change. Human interventions to assist nature in its capacity to adapt to climate change bring significant benefits in the form of ecosystem services. Communities that use incentives and policy tools to increase low-impact development and natural infrastructure will see resilience dividends.

Continued population growth and urbanization could also lead to higher and disproportionate levels of climate risk for vulnerable populations. Addressing the fundamental determinants of human health, particularly those related to equity, and prioritizing the adaptation needs of vulnerable populations will contribute to achieving benefits that exceed the findings of traditional economic analyses.

Flooding in heavily urbanized areas remains one of the most significant climate-related impacts because it can disrupt numerous critical services. Updated information that helps to delineate high-risk areas can inform climate-smart decisions for development, including the location of future critical infrastructure and retrofitting of existing stock.

Cooperation and coordination between levels of government to support climate resilience planning and decision making makes adaptation more efficient. Continued training in professional planning, engineering, health, architecture, conservation and finance will help ensure that climate change is mainstreamed into

practice for different professions. This training will help make climate resilience an inherent component of economic growth.

The strong business and financial community in Ontario presents an opportunity to assess economic risks associated with climate change, mainstream climate change into enterprise risk management systems and business decision making, and ensure that financial holdings and investment portfolios are adequately disclosing climate risks to shareholders and investors.

Since climate change is a "society-wide" issue, consideration of adaptation is not limited to government or private sector decision-makers and professional institutions. Increasing awareness of the need for adaptation among homeowners and the general public will expand the scope of adaptation actions and support their successful implementation.

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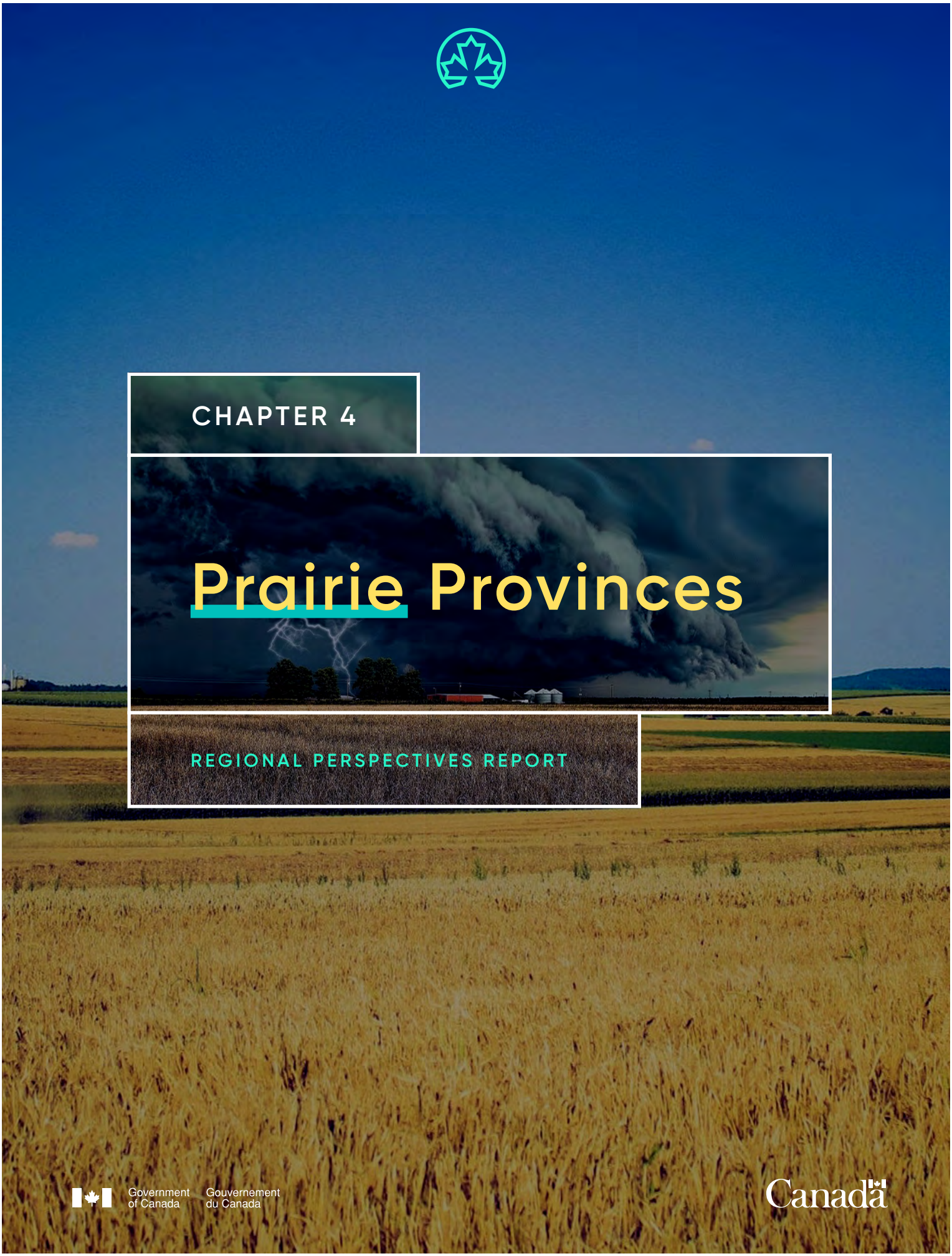

CHAPTER 4

Prairie Provinces

REGIONAL PERSPECTIVES REPORT

Government of Canada
Gouvernement du Canada

Canada

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Key messages

Prairie ecosystems will shift and transform as the climate warms (see Section 4.2)

As species respond to climate change, large regions of boreal forest could transition to aspen parkland and grassland ecosystems, while entire mountain ecosystems could disappear. Although biodiversity could increase overall, some species will be lost if the rate of warming exceeds their ability to adapt. Adaptation interventions are based mainly on standard conservation strategies—such as reduction of anthropogenic and other stressors and disturbances—and minimizing barriers to movement.

Floods, drought and wildfires are getting worse (see Section 4.3)

Extreme weather events of amplified severity will likely be the most challenging consequence of climate change in the Prairie Provinces. The impacts of flooding, drought and wildfire in recent years are unprecedented, and climate models suggest an increased risk of these events in the future. Provincial and municipal governments have responded by proposing policies, structures and practices to reduce the impacts of future extreme weather events.

Collaborative water management reduces negative impacts (see Section 4.4)

Regional land-use policy and planning, as well as emergency preparedness, are critical for reducing the impacts of flooding and drought in the Prairie provinces. Collaboration is needed among all levels of government, and with stakeholders such as watershed stewardship groups, rural municipalities and conservation districts, to implement these adaptation measures and to promote practices that prevent or minimize adverse effects of water excesses and shortages.

Climate change brings both benefits and threats to agriculture (see Section 4.5)

Prairie agriculture, particularly crop production, may benefit from higher temperatures and a longer growing season. Achieving net benefits will require adaptation to limit the impacts of climate extremes, including on water availability, and the increased risk of pests, vector-borne diseases and invasive species. Although agricultural producers are highly adaptable to fluctuations in weather and climate, barriers to adaptation include limited information and awareness of climate change impacts, combined with limited financial resources and institutional support.

Social groups have unique vulnerabilities and strengths (*see* Section 4.6)

The impacts of climate change may exacerbate existing societal inequities, especially among Indigenous peoples, women, people of low socio-economic status, youth and the elderly. Public policy and adaptation planning should consider the unique vulnerabilities and strengths of these social groups, and also the means by which race, age, gender and poverty amplify vulnerability or resilience to climate hazards.

Adaptation planning helps to reduce climate risks (*see* Section 4.7)

Cities are at the forefront of adaptation and resilience planning in the Prairie provinces. Governments and businesses have begun to assess climate risks and develop adaptation strategies, but few sector-specific plans and policies consider future climate risks, leaving some firms, governments and sectors unprepared. Assessing the effectiveness of adaptation measures and meaningful reporting would help achieve climate-resilient communities and local economies.

4.1 Introduction

The provinces of Alberta, Saskatchewan and Manitoba represent about one third of the area of Canada and lie south of 60 degrees latitude. This large region is known as the "Prairie provinces" or simply the "Prairies", although only about 30% of the region lies within the Prairie Ecozone (see Figure 4.1). The ecosystems and landscapes of the Prairie provinces include the Rocky Mountains, boreal and cordilleran forests, semiarid interior plains, aspen parkland, subarctic shield and Hudson Bay lowlands (see Figure 4.1). The region features considerable economic and social diversity—including Canada's third largest provincial economy (Alberta) and the nation's fourth and fifth most populated cites (Calgary and Edmonton, respectively)—in contrast to the rural agricultural communities of the southern prairies, and the mining and forestry industries and remote, mostly Indigenous communities of the northern part of the region. Extraction and processing of non-renewable resources (e.g., oil and gas, mining) are a major economic driver, representing the largest contributing sector to the economies of Alberta and Saskatchewan (Western Economic Diversification Canada, 2018), whereas Manitoba's economy is more varied. The economies of all three Prairie provinces are becoming more diverse, with a downturn in the oil and gas sector in recent years and more local manufacturing and high-tech industries.

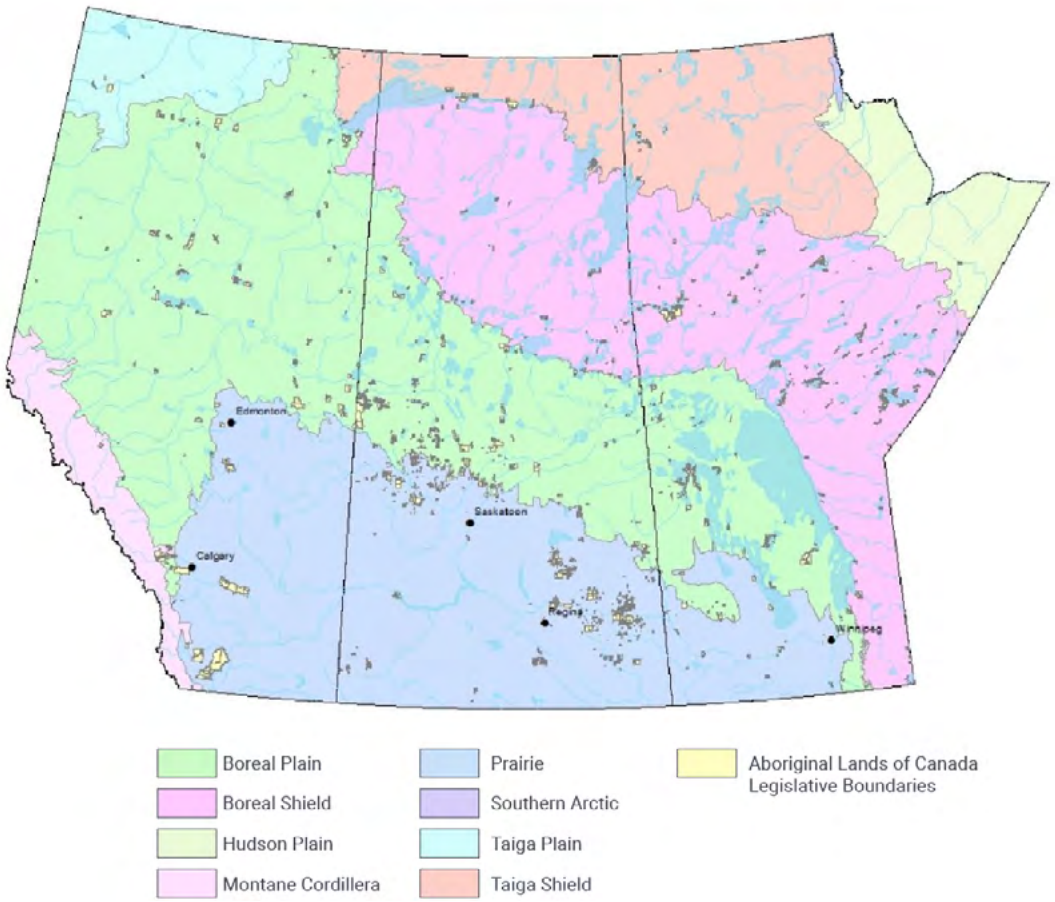

Figure 4.1: Map of the Ecozones of the Prairie Provinces, also showing the Aboriginal Lands of Canada Legislative Boundaries, and major cities, rivers and lakes. Source: Prairie Adaptation Research Collaborative.

In assessing existing knowledge of climate change impacts and adaptation, the following characteristics of the Prairie provinces emerge as important determinants of vulnerability to climate change:

- The Prairies, and western Canada generally, have had the strongest warming to date across southern Canada, especially in winter;
- More than 80% of Canada's agricultural land and most of the country's irrigated agriculture is located in the Prairies;
- Water resources, ecosystems and resource economies are subject to large seasonal and interannual variations in climate, and especially to departures from normal conditions (e.g., drought);
- Historically, the region has seen a population shift from rural to urban areas, and in-migration from other provinces and beyond Canada in response to economic opportunities. From 2007–2017, the four fastest growing cities in Canada were the major cities in Alberta and Saskatchewan. Western Canada has led the nation in the highest rate of employment of landed immigrants (Statistics Canada, 2018a).
- Most of the population and commercial activity is in the southern Prairies, which is also the part of the region with the most limited and variable water supply. Most rural communities depend on local runoff and groundwater. Urban communities access water from the major rivers and lakes, which also support the main industries, such as oil sand mining in northern Alberta.
- The Prairies are home to 39.2% (656,970) of Canada's Indigenous population—including 45.8% (246,485) of Canada's Métis population—with the majority of Indigenous people living off-reserve (Statistics Canada, 2019a). More than 10% of the Indigenous population in the region lives in Winnipeg and Regina (Statistics Canada, 2019b). The Prairie provinces are entirely covered by numbered treaties, which are the basis for the relationship between First Nations and the Government of Canada.

Recent extreme weather events in the Prairie provinces include the most costly natural disasters in Canadian history *(see* Figure 4.2; SeaFirst Insurance Brokers, 2018). The 20 most costly weather events in Canada since 1983 are listed in Table 4.1; of these events, 13 occurred in the Prairies. Six of the top 10 have occurred in the Prairies region since 2010. The concentration of losses in Alberta largely reflects the fact that its population is more than four times larger than Saskatchewan's or Manitoba's. While the cost associated with damage from recent storms, flooding events and fires—notably the 2013 flood in Calgary and 2016 wildfire in Fort McMurray—is in the billions of dollars, drought is the most costly type of weather event in terms of loss and damage in the Prairies. The dollar amounts listed in Table 4.1 represent insured losses. On the other hand, the socio-economic impacts of drought are widespread, both geographically and throughout the economy. During the drought year of 2002, crop losses alone were in the billions of dollars, with negative net farm income in Saskatchewan and zero farm income in Alberta (Wheaton et al., 2008).

Table 4.1: The twenty most damaging Canadian weather events since 1983

DATE	PLACE	EVENT TYPE	LOSSES ($ MILLION)*
May 3–19, 2016	Fort McMurray, AB	Fire	3,899.1
January 1998	Southern Quebec	Ice storm	2,022.3
June 19–24, 2013	Southern Alberta	Flooding, water	1,737.4
July 8, 2013	Greater Toronto Area, ON	Flooding, lightning, water	1,004.6
August 19, 2005	Southern Ontario	Hail, tornadoes, wind	779.7
May 4, 2018	Hamilton, ON; Greater Toronto Area, ON; Southern Quebec	Windstorm, water	680.0
May 15–16, 2011	Slave Lake, AB	Fire, windstorm	587.6
August 7, 2014	Central Alberta	Hail, lightning, water, windstorm	582.3
August 12, 2012	Calgary, AB	Hail, lightning, water	571.8
July 12, 2010	Calgary, AB	Hail, flooding, lightning, windstorm	557.7
September 7, 1991	Calgary, AB	Hail	552.2
July 30–August 1, 2016	Calgary, AB; Fort McMurray, AB; Yorkton, SK; Melville SK; Winnipeg, MB	Hail, lightning, water, windstorm	480.5
August 1–3, 2009	Calgary, AB; Camrose AB	Hail, lightning, water, windstorm	404.1
June 6–8 and 17–19, 2005	Alberta	Flooding	374.0
September 21, 2018	Dunrobin, ON; Nepean, ON; Ottawa, ON; Gatineau, QC	Flooding, hail, water, windstorm	334.0

DATE	PLACE	EVENT TYPE	LOSSES ($ MILLION)*
July 23, 1996	Outaouais, QC	Hail, wind	310.9
July 25–August 14, 1993	Winnipeg, MB	Flooding	288.1
July 31, 1987	Edmonton, AB	Tornado	282.5
July 21, 2015	Central Alberta	Flooding, hail, water, windstorm	273.3
Summer 2003	British Columbia	Forest fire	259.5

**Losses are in 2018 $.*

SOURCE: IBC WEATHER FACTS, 2019.

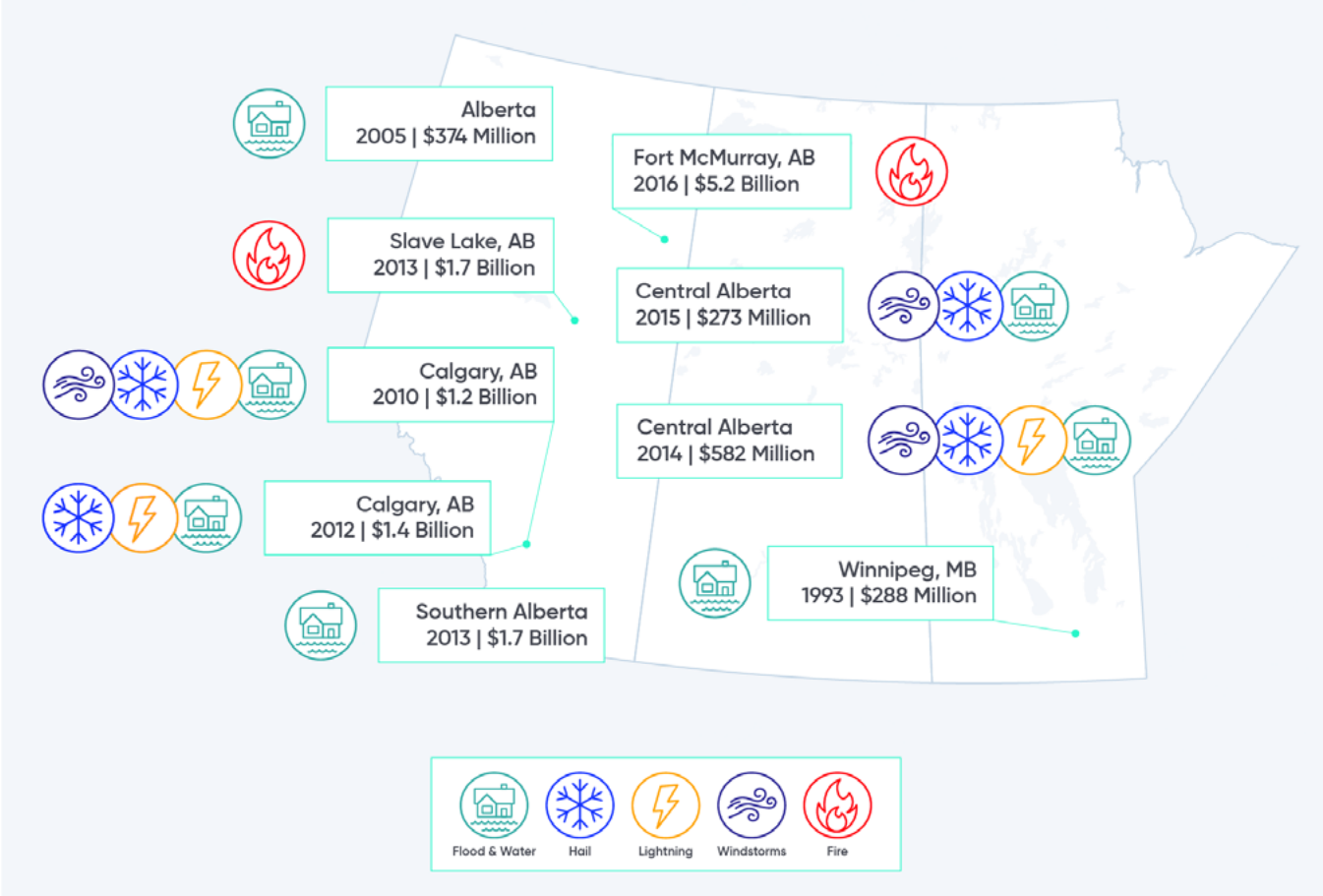

Figure 4.2: Economic impacts of the most damaging extreme weather events to date in the Prairie provinces. Costs represent insured losses in 2018 $. Total costs are generally much higher. Data source: Insurance Bureau of Canada, 2019.

With climate change, the Prairie provinces are projected to be much less cold than at present, with increased total precipitation, although mostly in winter and spring (Zhang et al., 2019). Evaporation and transpiration will also increase with warmer temperatures, leading to more frequent and intense droughts and soil moisture deficits over the southern Prairies during summer (Cohen et al., 2019). There will be far fewer cold days, higher maximum temperatures and heavier rainfall events, as warming amplifies the already wide variability in the prairie hydroclimate *(see* Figure 4.3). This natural variability underlies the changes caused by a warming climate, and accounts for differences among future projections of temperature and precipitation that cannot be explained by the use of different models and greenhouse gas emissions scenarios (Barrow and Sauchyn, 2019).

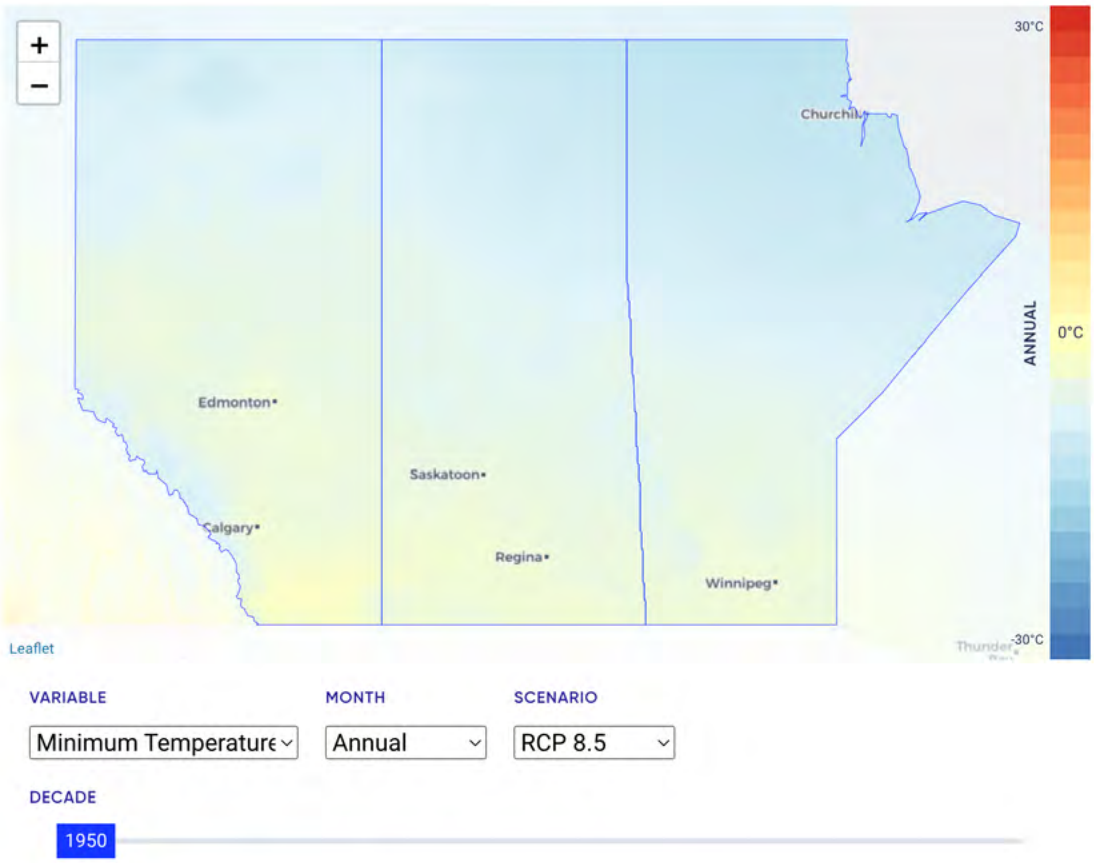

Figure 4.3: Regional map of the Prairie region illustrating historical and projected data using RCP8.5 for key climate change variables—minimum winter temperature, growing degree days and maximum one-day precipitation—from 1951 to 2100. Source: climatedata.ca

This chapter builds on the Prairies chapter in the previous national assessment (Sauchyn and Kulshreshtha, 2008) by emphasizing adaptation processes and planning, and highlighting progress made over the past 10 years. It focuses on knowledge that enables better adaptation, resilience planning and policy development. A recurring theme in this chapter is the distinction between the impacts of and adaptation to slow-onset climate change—such as changes in average temperature and precipitation patterns—versus shifts in climate variability and the occurrence of extreme weather events, which are associated with natural hazards such as floods, drought and wildfire.

4.2 Prairie ecosystems will shift and transform as the climate warms

As species respond to climate change, large regions of boreal forest could transition to aspen parkland and grassland ecosystems, while entire mountain ecosystems could disappear. Although biodiversity could increase overall, some species will be lost if the rate of warming exceeds their ability to adapt. Adaptation interventions are based mainly on standard conservation strategies—such as reduction of anthropogenic and other stressors and disturbances—and minimizing barriers to movement.

Climate change will result in broad-scale ecosystem shifts across the Prairie provinces. These shifts will lag behind changes in climate by decades, and will therefore continue well into the future. The extent to which forest, grassland and parkland ecosystems shift will depend on the rate of climate change and the success of adaptation measures. Such measures include planting tree species that are adapted to dry conditions and removing human-caused barriers to range shifts, such as those caused by industrial and urban development. Some species may be lost as ecosystems transition, while in the mountains, entire ecosystems could disappear as their climate envelopes rise to higher elevations. On the other hand, the climate associated with grasslands is expected to expand, suggesting that the many at-risk species in this region could benefit, with appropriate protection and restoration of grassland habitat.

4.2.1 Ecosystem shifts

Over the long term, plants respond to climatic changes by shifting their ranges. These shifts are mediated through competition and other interspecific interactions (Hargreaves et al., 2014; HilleRisLambers et al., 2013). Competition ensures that the plants that exist in any particular area are those best adapted to the local climate and site conditions. When the climate regime changes, the competitive balance is disrupted and must be re-established (Wiens et al., 2010; Martinez-Meyer et al., 2004). At the macro scale, this manifests as a slow directional shift in the distribution of plant communities along the prevailing climatic gradient (Kelly and Goulden, 2008). This is often described as plants "tracking" their climatic envelope, although it is actually a process driven by competition *(see* Ecosystem Services chapter and Box 4.1).

Box 4.1: Transitional mechanisms

Species range shifts will lag significantly behind changes in climate (Gray and Hamann, 2013). This is because ecological systems have inertia, largely an effect of "priority of place" (HilleRisLambers et al., 2013; Suttle et al., 2007). Established plants are not easily displaced by new arrivals, even if the climate has become suboptimal for them (Urban et al., 2012). Superior competitors will eventually prevail, but may need to wait for

a window of opportunity to be provided by the mortality of existing plants; this transition can take decades in forest ecosystems.

Aspen provide a useful example. Surveys along the eastern slopes of the Rocky Mountains have identified aspen seedlings growing at an elevation as high as 1500 m, which is 200 m higher than previously recorded (Landhäusser et al., 2010). All of these seedlings were growing within forestry cutblocks, which provided the conditions needed for aspen establishment. Aspen was unable to establish within adjacent mature forest stands, even though climatic conditions were similar. The implication is that the potential range of aspen has already expanded as a result of the warming that has occurred in recent decades; however, the utilization of this new range is being impeded by the presence of existing vegetation. Most species are likely to experience these sorts of lag effects (Gray and Hamann, 2013; Bedford et al., 2012).

The aspen example demonstrates that disturbance rates will be a key factor governing the rate of ecological transition (Stralberg et al., 2018; Schneider et al., 2009; Hogg et al., 2008). Anything that kills or seriously weakens existing vegetation—including disturbances such as fire, severe drought, insect outbreaks or wind-throw—provides an opportunity for competitive rebalancing and range shifts. Conversely, areas that remain undisturbed will transition much more slowly, despite progressive changes in climate. The rate of natural disturbances is expected to increase under climate change, potentially hastening the rate of ecological transition (Boucher et al., 2018; Stralberg et al., 2018; Wotton et al., 2017).

Given the role played by disturbances in these ecological transitions, ecosystem boundaries will not shift as a solid front. Instead, ecological transitions are likely to be widely distributed and patchy, reflecting the scattered distribution of natural disturbances (Schneider et al., 2009). The types of transitions that occur within disturbed sites will depend on the degree of climatic warming that has occurred up to that point, and on local factors such as soil moisture and nutrient levels at the time of the disturbance and the availability of seed sources.

Dispersal ability is another factor limiting vegetation responses to climate change (Urban et al., 2012). The rate at which plants can invade new landscapes—given suitable conditions—depends on the distance that their seeds can travel and the time required for seedlings to mature and produce seed. Potential for the disruption of co-dependent relationships between species (e.g., pollinators and flowering plants) could also affect seed germination and dispersal patterns. Given the rapid rate at which the climate is warming, many species will be unable to disperse fast enough to keep pace with the leading edge of their preferred climatic conditions (Corlett and Westcott, 2013). The ones that do are likely to be pioneer species, like fireweed, with the ability to exploit new and potentially distant habitats. A corollary is that climate change is expected to lead to the expansion of native species and the arrival of new invasive species (Walther et al., 2009).

Because dispersal ability varies among species, their ranges will shift at different rates. This means that we can expect novel combinations of species to occur within ecosystems during the transitional period (Urban et al., 2012). The movement of intact ecological units, as predicted by simple bioclimatic models, is an oversimplification (Schneider et al., 2015).

Soil moisture levels control the broad-scale vegetation patterns in the Prairie provinces (Hogg and Hurdle, 1995; Hogg, 1994). A mixed-grass prairie occupies the driest areas of the region, transitioning to taller grasses, aspen parkland, closed aspen forests and boreal forest as moisture levels increase (Schneider, 2013; Thorpe, 2011). Warmer temperatures will increase evaporation and transpiration during the growing season, resulting in lower soil moisture unless it is offset by increases in seasonal precipitation. While annual precipitation is projected to increase across most of the region, much of this will occur early in the calendar year and is likely to be insufficient for preventing soil moisture decreases by late summer (Bonsal et al., 2019).

The northern forests of the Prairie provinces receive much less precipitation than do most forests in British Columbia and eastern Canada (Hogg and Hurdle, 1995). Lower mean temperatures and rates of evaporation explain the positive water balance and forest vegetation. However, as temperatures rise and soil moisture declines, the forest will transition to a more open ecosystem type. There is a strong likelihood that large areas of boreal forest will eventually transition to aspen parkland and grassland, even under the lowest warming scenarios (Stralberg et al., 2018; Ireson et al., 2015; Schneider et al., 2015; Hogg and Hurdle, 1995).

Vegetation communities will track their preferred climatic envelopes as they shift northward and upslope as a result of progressive warming. The rate and spatial pattern of vegetation transitions depend largely on warming rates, natural disturbance rates and the individual species' dispersal rates *(see* Box 4.1). Ecosystem transitions are expected to be dramatic in Alberta *(see* Figure 4.4), reflecting the fact that most low-elevation areas in northern Alberta are already near the climatic threshold between forest and grassland. Open prairie and farming communities already exist along the Peace River in northern Alberta. Northern Saskatchewan and Manitoba receive more precipitation than northern Alberta, and are therefore less likely to undergo similar transitions. However, the southern fringe of the boreal forest will move substantially northward, and island forests in the southern parts of these provinces are unlikely to remain forested (Ireson et al., 2015; Hogg and Bernier, 2005; Henderson et al., 2002). As the climate warms, southern parts of the Prairie provinces will remain as grassland ecosystems, but the species composition will shift in areas that have not been converted to agriculture. Under a low emissions scenario, the grassland ecosystems in this region may eventually resemble the grassland communities of Montana and North Dakota (Thorpe, 2011). Higher levels of warming may result in an influx of species that are not native to Canada *(see* International Dimensions chapter; Thorpe, 2011).

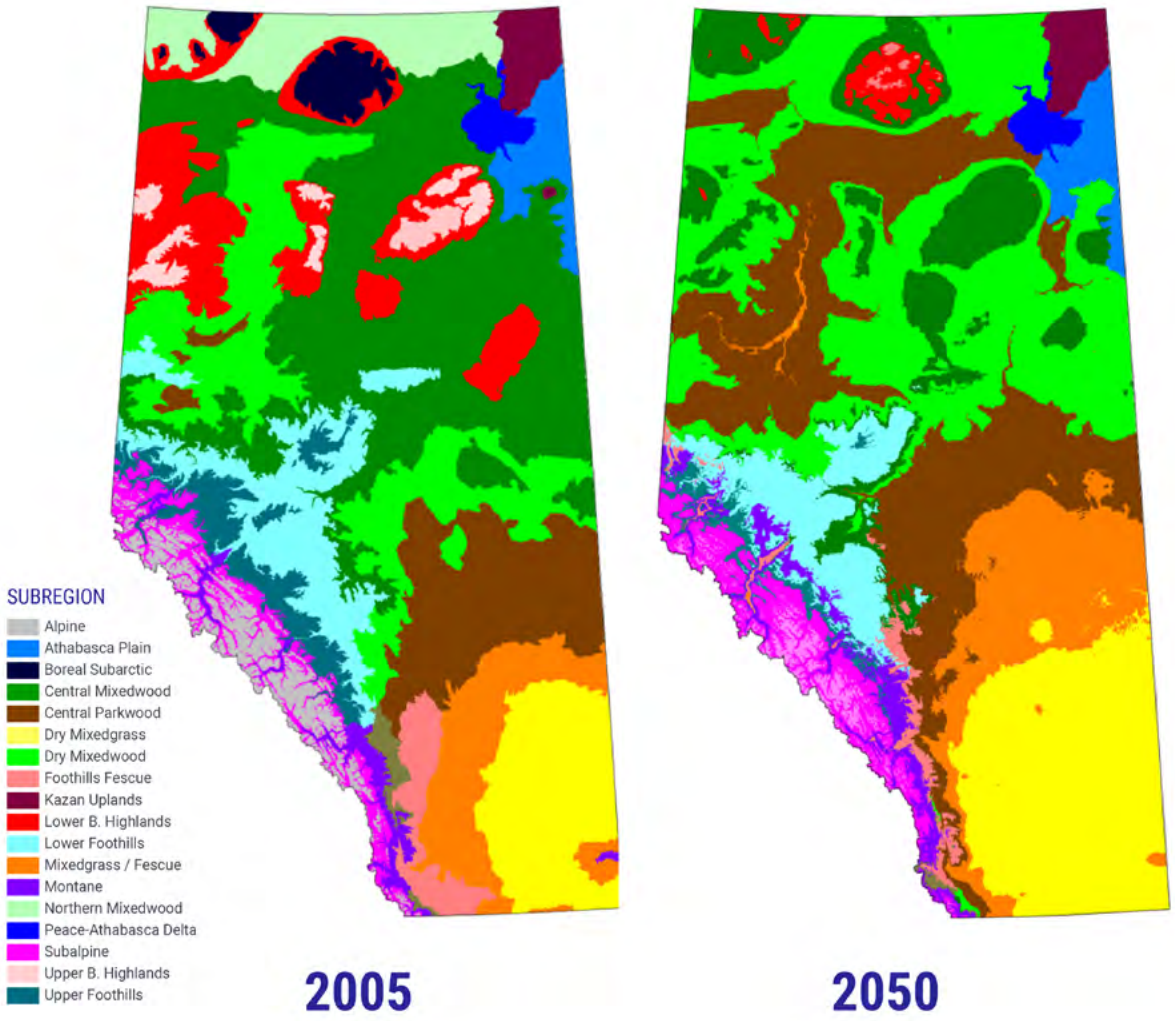

Figure 4.4: The distribution of Alberta's major ecosystem types in 2005 (left) and bioclimatic envelope model projections of these ecosystems for the 2050s (right), under a medium emissions scenario (ECHAM5-A2). Source: Adapted from Schneider and Bayne, 2015.

Bioclimatic envelope model projections, such as those presented in Figure 4.4, predict the equilibrium redistribution of ecosystems under future climatic conditions for a medium emissions scenario. However, since the climate is expected to continue changing until at least well into the next century, we can expect a prolonged period of transition. Ecosystems will be complex mixtures of old and new elements, blurring ecosystem boundaries and increasing habitat diversity in most regions (Savage and Vellend, 2015; Berteaux et al., 2010).

Increased evaporation and a longer snow-free period will reduce the average water levels of wetlands and increase the amount of time that seasonal wetlands are dry (Johnson et al., 2010; Larson, 1995). These changes will be most pronounced in the southern grasslands, where summer moisture deficits are already

the norm. In northern areas, peatlands predominate and have considerable resistance to evaporation losses (Kettridge and Waddington, 2014). Nevertheless, the overall area of peatlands will slowly contract (Schneider et al., 2015). In all areas, the amount of change will be proportional to the amount of warming.

4.2.2 Animal responses

Climate influences animal distributions both directly and indirectly, with impacts differing between habitat generalists and habitat specialists. For generalists, the direct effects of warming are likely to be most important. For example, white-tailed deer are found across many Prairie biomes, from boreal forests to grasslands. The northern extent of their range is thought to be determined mainly by winter severity, which affects survival and fecundity (Dawe and Boutin, 2016). Thus, warmer winters are likely to lead to range expansion long before vegetative communities have responded. Evidence of such climate-induced range expansion is already accumulating in the Prairie provinces and in adjacent regions to the north (Veitch, 2001; Dawe and Boutin, 2016).

For other animal species, habitat suitability is the key factor governing range shifts (Kissling et al., 2010; Nixon et al., 2016). For example, the climate envelope for the burrowing owl—an endangered grassland species at the northern extent of its range in the Prairie provinces—is projected to move northward fairly rapidly (Fisher and Bayne, 2014). However, the owls will not be able to utilize this expanded potential range until entire grassland ecosystems—including appropriate vegetation and prey species—are in place. As such, despite their high mobility, many animal species will be unable to respond to climate any faster than the plant species they ultimately depend upon (Nixon et al., 2016).

4.2.3 Biodiversity implications and adaptation strategies

Species diversity in Canada declines with increasing latitude and is, on the whole, relatively low compared to many other countries (Willig et al., 2003). A northward movement of climate envelopes is expected to boost biotic productivity and species richness at all latitudes (Jia et al., 2009; Savage and Vellend, 2015). However, not all ecosystems and species will benefit. For example, alpine ecosystems in the Rocky Mountains will be compressed as suitable climate conditions rise in elevation towards the summits of the mountain peaks. The grassland ecosystems, with the largest number of species at risk in the Prairie provinces, will benefit as they expand into the southern boreal region (Hogg and Hurdle, 1995; Ireson et al., 2015).

These expectations of biodiversity patterns are subject to a major caveat. Individual species must have the ability to keep pace with climatic and ecological changes as they occur; otherwise, warming may result in the loss of species rather than a reshuffling of species. Although Canadian species have demonstrated the ability to adapt to dramatic climate changes in the past, the current unprecedented rate of change may result in some species being unable to adapt quickly enough, especially those with low dispersal ability, low rates of reproduction and low levels of genetic variation (Pearson et al., 2014).

The landscapes of the Prairie provinces are also greatly impacted by human activities, which limit the ability of species to adapt. Concern is greatest for species at risk, which are already struggling to remain viable under current conditions. The added stress imposed by rapidly changing climatic conditions exacerbates other anthropogenic impacts on species habitats (Hof et al., 2011). For example, the burrowing owl is currently declining in abundance as its habitat is contracting southward towards the core of its range in the US (COSEWIC, 2006), despite the fact that changing climate conditions suggest it should be able to expand along the northern edge of its range as conditions become suitable. Moreover, its small remnant populations in Canada may lack the resilience needed to withstand extreme weather events (Oliver et al., 2013; Fisher et al., 2015).

Species also face physical barriers that impede range shifts (Hof et al., 2011; Melles et al., 2011). Habitat deterioration presents the most widespread barrier and, while not completely blocking movement, slows the pace of adaptation. For example, the ability of grassland species to track their preferred climate is likely to be hindered by the presence of intensively managed agricultural land (Nixon et al., 2016). For fish, stream fragmentation may reduce access into climatically optimal watercourses (Park et al., 2008).

With appropriate management support, the proportion of species that are "left behind" may be relatively small under low emission scenarios. However, widespread adaptation failure is a real possibility under high emission scenarios, which will result in unprecedented changes (Corlett and Westcott, 2013). Available adaptation measures are, for the most part, components of the standard conservation toolkit (Heller and Zavaleta, 2009; Schneider, 2014). A key approach is to reduce anthropogenic stressors—such as habitat loss—to improve the general vitality and resilience of species, thereby enhancing their adaptive capacity.

Management strategies designed to minimize the impacts of human disturbances are paramount. In managing forest and grassland ecosystems, it is important that conservation objectives be dynamic, rather than planned based on historical conditions. The challenge is to develop a planning system that embraces flexibility, while safeguarding against activities that are inconsistent with the aims of conservation. There is also a need to incorporate climate change into the regulatory and policy frameworks supporting conservation. The Canadian Council of Forest Ministers developed a toolbox to assist forest managers in determining the vulnerability of their forest management systems to climate change. The centrepiece of the toolbox is a guidebook (Edwards et al., 2015) that walks forest managers through vulnerability assessment and adaptation planning.

Another important strategy is to remove or minimize barriers to movement, such as by restoring previously disturbed landscapes. Strategically placed protected areas can also facilitate species movements (Nantel et al., 2014; Nunez et al., 2013). Species that are unable to effectively track climatic changes may require active support in the form of assisted migration (Gallagher et al., 2015; Warren and Lemmen, 2014). Assisted migration is a feasible adaptation option that can be implemented now in preparation for future impacts—such as drought or warmer temperatures—and resulting changes in habitat (Ste-Marie et al., 2011; Warren and Lemmen, 2014). This form of migration can comprise the following: i) assisted population expansion, by moving populations (i.e., seed) from other locations to sites within the current species range to improve productivity and health as the climate changes; ii) assisted range expansion, by moving seed to locations somewhat beyond the species' current distribution, where the climate in the near future is expected to be

suitable for the growth of the species; and iii) translocation of exotics, by moving a species far beyond its current distribution to a location in which it has not been established in the past (e.g., to a new ecoregion or a different continent) *(see* Ste-Marie, et al., 2011 for a comprehensive review of assisted migration in the Canadian context).

4.3 Floods, drought and wildfires are getting worse

Extreme weather events of amplified severity will likely be the most challenging consequence of climate change in the Prairie Provinces. The impacts of flooding, drought and wildfire in recent years are unprecedented, and climate models suggest an increased risk of these events in the future. Provincial and municipal governments have responded by proposing policies, structures and practices to reduce the impacts of future extreme weather events.

Recent extreme weather events in the Prairie provinces—including flooding, drought and wildfire—have been the costliest natural disasters in Canadian history. This includes record dry months and historically high water levels. An increased frequency and severity of extreme weather events will be superimposed upon a more gradual change in average conditions, requiring adaptation to prepare for a wider range of weather conditions and to shifts in the distribution of water resources. Ultimately, water shortages would be the most damaging, resulting in social and environmental impacts, along with economic losses from lost productivity in the agriculture, forestry, energy and mining sectors (i.e., extraction of oil sands and solution potash mining).

4.3.1 Weather hazards

Extreme weather presents the most immediate climate risk for the Prairie provinces, as is evident from the catastrophic events that have taken place over the past 10 years *(see* Figure 4.2). Extremes in precipitation and temperature lead to impacts, such as flooding, drought and wildfire *(see* Box 4.2). Given the vast size and hydroclimatic diversity of the Prairie provinces, it is not unusual for parts of the region to be experiencing drought and wildfire at the same time, while other communities are being flooded (Brimelow et al., 2014). Extreme weather events superimposed on longer-term trends of changing average climate conditions have significant social and economic impacts, challenging the sustainable management of water, forests and soil.

Climate warming may have profound and immediate impacts on wildfire activity. The area of forest burned in Canada has already increased, mainly due to human-caused warming (Gillett et al., 2004). Warmer temperatures lengthen the fire season (Albert-Green et al., 2013) and are associated with increased lightning strikes (Romps et al., 2014). More importantly, higher temperatures lead to drier fuels, as moisture is lost

from soil and plants to the warmer atmosphere (Flannigan et al., 2016). The amount of moisture held by the atmosphere increases almost exponentially as the temperature rises. Almost none of the future scenarios include sufficient increases in precipitation to compensate for the drying effect of warmer temperatures. Drier fuels make it easier for fires to start, spread and burn more intensely, making them more difficult to extinguish (*see* Video 4.1).

Video 4.1: Métis wildland firefighters are deeply connected to the land, their culture, and the impacts of climate change across the Canadian prairies. Source: Métis National Council and Prairie Climate Centre, 2020. https://youtu.be/Px4eDr8ozys

Box 4.2: Assessing the risk of flooding and other natural hazards in Saskatchewan

The province of Saskatchewan completed a comprehensive assessment of natural hazards in 2018 (Wittrock et al., 2018). Aggregate risk—the combination of likelihood and impact—was evaluated for ten climate-related hazards (*see* Table 4.2). Likelihood was based on the analysis of weather records and climate model projections, while the impact level was estimated using data about past weather events and information obtained from consultations with stakeholders and sector experts.

Table 4.2: Degree of aggregate risk in Saskatchewan from climate-related natural hazards

NATURAL HAZARD	CURRENT RISK[1]	MID-CENTURY RISK[2]
Drought	High	High to extreme
Convective summer storms	High	High to extreme
Forest fire	Moderate to high	Moderate to high
Winter storms	Moderate to high	Moderate to high
Overland flooding	Moderate	Moderate to high
Grass fire	Moderate	Moderate to high
Plains runoff flooding	Moderate	Moderate
Lake flooding	Moderate	Moderate
Mountain runoff flooding	Low to moderate	Low to moderate
Groundwater flooding	Low	Low

1 Plausible worst-case scenario based on historic events

2 Risk under projected mid-21st century climatic conditions

SOURCE: WITTROCK ET AL., 2018.

This analysis indicates that future risk of drought and summer convective storms rises to "extreme" as warming amplifies the severity of these weather events. This effect is also seen in the increased risk from overland flooding as rainfall becomes more intense. Floods will increasingly be generated by heavy rain or rain on snow, in contrast to the historical prevalence of flooding being the result of spring snowmelt runoff (Pomeroy et al., 2015).

This risk assessment applies to the neighbouring Prairie provinces with two notable exceptions. The risk of mountain runoff flooding is much higher for Alberta's urban centres, given their greater proximity to the Rocky Mountains. In Manitoba, the risk from plains runoff flooding is higher than in Saskatchewan, specifically in the Red River and Assiniboine River basins. Otherwise, the Prairie provinces experience similar exposure to and consequences from drought, wildfire and storms—the weather-related hazards that represent the greatest near-term risk in the region.

4.3.2 Hydrological hazards

Large interannual variability and extreme hydroclimatic events are characteristic of the Prairie provinces. Simultaneous wet and dry conditions across the region are not uncommon; they occur, for example, when high pressure in the western Prairies diverts moist air masses towards the east (e.g., Liu et al., 2004; Rannie, 2006; Szeto et al., 2011).

Both gradual, long-term changes in water levels and extreme fluctuations around the changing baseline will have impacts and require adaptation. Water allocation and the design of storage and conveyance structures—such as reservoir and irrigation pipes—are based mainly on average seasonal water levels. Otherwise, water resources are managed to prevent the adverse impacts of flooding and drought.

There has been much analysis of the most recent multi-year drought in the Prairie provinces, which spanned the period from 1999–2004 (e.g., Hanesiak et al., 2011; Bonsal et al., 2011; Wheaton et al., 2008). This was followed by a period of relatively wet conditions from 2005–2019, with the exception of some intense droughts of seasonal duration, including from summer 2008 to winter of 2009–2010 (Wittrock et al., 2010), summer 2015 (Szeto et al., 2016), spring/summer 2017 (Jencso et al., 2019), and spring/summer 2019 (Agriculture and Agri-Food Canada, 2019). While drought and flooding are difficult to predict, their probability is strongly linked to periodic fluctuations in sea surface temperatures in the Pacific Ocean, known as the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) *(see* Box 2.5 in Bush et al., 2019). Uncertainty in projected future precipitation amounts and extremes depends largely on the ability of the models to simulate the internal variability of the regional climate—such as changes in the teleconnections between ocean–atmosphere oscillations (i.e., the ENSO and PDO) and in the regional hydroclimate (Barrow and Sauchyn, 2019)—and, to a lesser extent, on the use of different models and greenhouse gas emissions scenarios.

The impacts of water excesses and deficits differ with respect to the timing, duration, intensity and extent of flood and drought events. Meteorological drought (lack of rain) can immediately affect dryland farming, while hydrological drought (low water levels) affects irrigation, municipal and industrial water supplies. The cumulative impacts of a long period of low water levels contrast with the effect of short, intense drought. Flooding has been most damaging along the Red River in Manitoba and the rivers flowing from the Rocky Mountains, where population centres are concentrated. In the Prairies, however, inundation of agricultural land is common given the large area of depression storage (including sloughs and wetlands). A torrential rainstorm near Vanguard, SK on July 3, 2000, saw 375 mm of rain fall in 8 hours, with an estimated 62% of that water retained on the landscape (Hunter et al., 2002). While drought results in crop losses over large areas, flooding can prevent the sowing of crops, as occurred in 2011 over 5.5 million hectares, mostly in Manitoba (Brimelow et al., 2014). The Quill Lakes of east-central Saskatchewan have risen to such an extent that they are now one large lake inundating thousands of hectares of farmland, railroads and provincial highways (Water Security Agency, 2016).

Studies of the 2015 drought (Szeto et al., 2016), 2013 floods in southwestern Alberta (Teufel et al., 2017; Pomeroy et al., 2015) and of the Assiniboine River Basin in Saskatchewan and Manitoba in 2014 (Szeto et al., 2016) concluded that these naturally occurring events were intensified by human-caused climate change. The analysis of rainfall data generated by climate models indicates that a warming climate will cause a significant

shift from historical values in the intensity, duration and frequency of rainfall events (Bonsal et al., 2019). For example, climate projections for Saskatoon reveal an increase in the intensity of short-duration extreme precipitation events and a decrease in the length of the return period between these events, with the most intense precipitation occurring towards the end of the 21st century under the RCP8.5 high emissions scenario (Alam and Elshorbagy, 2015).

An increase in rainfall intensity is one of the most consistent changes projected globally (IPCC, 2014), nationally (Zhang et al., 2019) and regionally (Gizaw and Gan, 2015). In the Prairies, farmland and infrastructure could be periodically inundated by excess precipitation in winter, which in future decades is increasingly likely to fall as rain. This excess water will occur as the warmer climate converges with the wet phase of the PDO and ENSO. Similarly, the amplitude of dry phases will likewise increase when there is an absence of rain, but also with higher temperatures than in the past (Tan et al., 2019). Climate projections suggest an increasing risk of drought in the Prairies, specifically in summer and fall (Bonsal et al., 2019). The worst-case future scenario for the Prairie provinces is the reoccurrence of consecutive years of severe drought, such as those that occurred in the 1930s and in preceding centuries (Sauchyn et al., 2015).

4.3.3 Societal impacts

The 2013 flooding in Calgary and the 2016 wildfire in Fort McMurray represent two of the costliest natural disasters in Canadian history, and provide dramatic examples of societal impacts arising from extreme weather. They also provide insight into actions being taken to reduce such impacts in the future *(see* Case Story 4.1), and highlight the linkages between climate change and natural disasters *(see* Case Story 4.2).

Case Story 4.1: Policies and measures for reducing flood risk in the City of Calgary

In 2013, Calgary experienced its largest flood since the turn of the 19th century (City of Calgary, 2017). Homes and businesses located in historic neighbourhoods and in the downtown core experienced devastating damage from riverine and stormwater flooding *(see* Figure 4.5). Traffic was disrupted, businesses were closed and community services were impacted. The resulting damage totalled $6 billion, including over $400 million to City of Calgary infrastructure (City of Calgary, 2017). The downtown core, in particular, was overwhelmed as power was lost and many businesses were not accessible for at least six days. Increased flood protection in this area is critical, especially considering that 124 corporate head offices are located there and provide more than 99,000 jobs—approximately 20% of the total number of jobs in Calgary (City of Calgary, 2019a).

Figure 4.5: Damage and recovery from flooding in Calgary in June 2013: a) near record-high water levels on the Bow River, b) disrupted urban transportation, c) flooded City Centre, and d) West Eau Claire flood wall.Photos courtesy of: Shutterstock.

Building flood resiliency is a top priority for the City of Calgary (City of Calgary, 2017). The City has taken a holistic approach to flood reduction, employing multiple lines of defence at the watershed, community and property levels. A comprehensive Flood Mitigation Measures Assessment, for example, identified the need for a combination of upstream, local and property-level adaptation measures, along with planning and policy to reduce flood risk and potential damages *(see* Figure 4.6; City of Calgary, 2017).

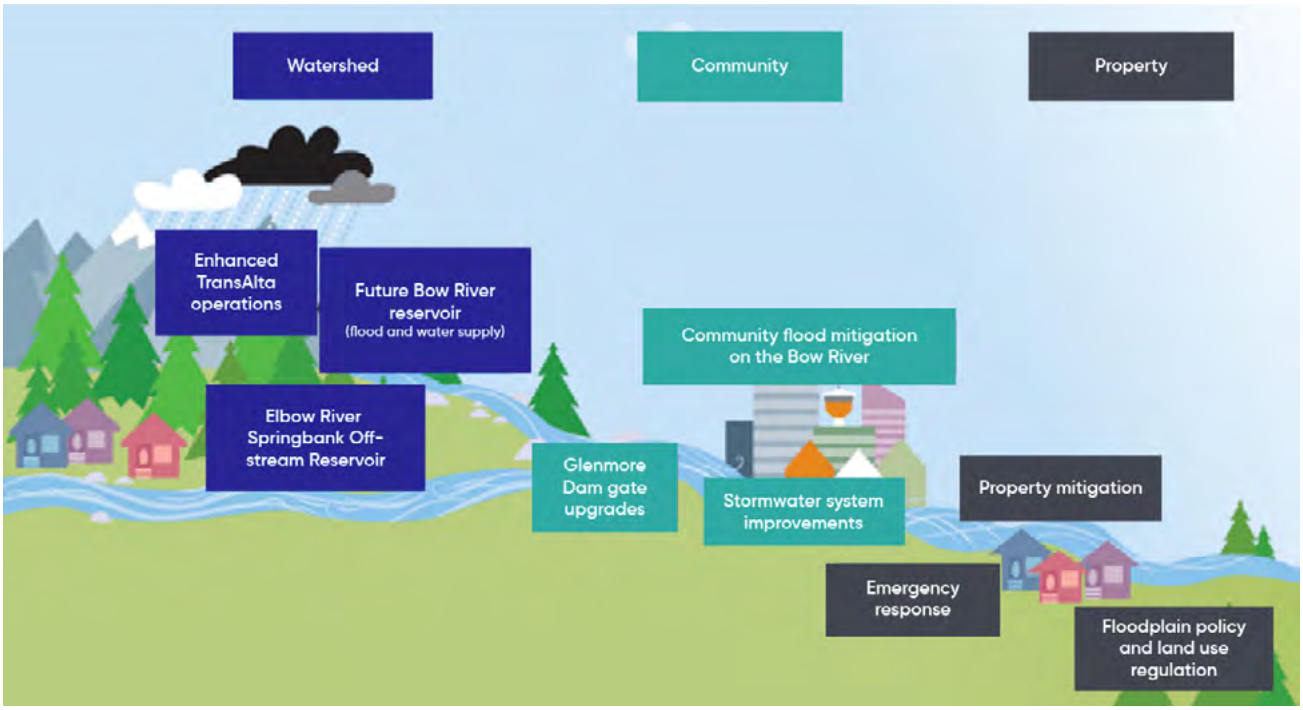

Figure 4.6: Visual representation of key adaptation measures from Calgary's Flood Resilience Plan. The plan uses a three-layered approach: 1) Upstream flood protection on the Bow and Elbow Rivers to increase water storage and help slow larger flows from the mountains, 2) Community-level flood protection through the installation and upgrading of permanent infrastructure, and 3) Property-level flood protection through changes to building regulations and bylaws, limiting types of development in flood-prone areas and public education. Source: City of Calgary, 2019b.

The City's Flood Mitigation Measures Assessment Report (City of Calgary, 2017) focused on protection against an event similar to the one experienced in 2013, with increased protection in critical areas such as the downtown and neighbourhoods at highest risk. A combination of barriers and flood-control operation protocols at existing reservoirs support the plan, although its success is also dependent on the ability of upstream reservoirs to provide a high level of protection, so as to avoid relocating communities. Stormwater flooding and a number of projects aimed at reducing stormwater back-up from flooded rivers have also been considered in the City's flood mitigation planning. In 2015, the Government of Alberta earmarked $150 million over 10 years for the City of Calgary to implement projects that reduce flood risk through the Alberta Community Resilience Program (Government of Alberta, 2015).

Case Story 4.2: The 2016 Fort McMurray wildfire

Wildfire is the keystone process responsible for shaping landscape diversity in the forests of the Canadian Prairies. However, wildfire can also be a threat to human life, communities and valuable commercial and industrial activities. A human-caused wildfire was discovered on May 1, 2016 about 7 km west of Fort McMurray, Alberta. This high-intensity, fast-moving wildfire spread into the town two days later *(see* Figure 4.7). The fire necessitated the evacuation of around 90,000 people, destroyed 2,800 structures and burned an area of 590,000 ha (slightly larger than Prince Edward Island) (Kochtubajda et al., 2017). The Fort McMurray fire was the costliest natural disaster in Canadian history, leading to insurable losses of just under $4 billion dollars and a negative impact on the national GDP *(see* Sector Impacts and Adaptation chapter).

Figure 4.7: The 2016 Fort McMurray wildfire. Source: Shutterstock.

Three factors influence wildfire activity: fuel (type, structure, amount and moisture), ignition (humans or lightning) and fire-conducive weather (typically hot, dry and windy) (Wotton et al., 2017). These three factors came together for the Fort McMurray fire with exceedingly dry fuel, human ignition and hot, dry and windy conditions.

More large and high-intensity wildfires, such as that experienced in Fort McMurray, are expected under current climate change projections (Flannigan et al., 2009; Zhang et al., 2019). Recent research suggests that the risk of extreme fires in western Canada has increased by a factor of 1.5 to 6 due to human-caused climate change (Kirchmeier-Young et al., 2017; Zheng et al., 2019), and that extreme springtime fire weather across western Canada is very likely an effect of human-caused warming (Tan et al., 2019).

The potential for interactions between society and fire will increase in a warmer world, requiring that people adapt to living alongside wildfire, while working to reduce its likelihood of threatening communities and other assets. Impacts from wildfires are a result of a warming climate and more development in forests. The number of days each year in which there is the potential for unmanageable fire is projected to more than double (between the periods 1971–2000 and 2081–2099) in some parts of the northern boreal forest in the Prairies (Wotton et al., 2017). Wildfire hazard can be reduced at the community level through actions such as reducing risks associated with vegetation located near structures and reducing the use of flammable building components (FireSmart Canada, 2020). FireSmart recommendations can be applied at the landscape level by using timber harvest and reforestation practices to break up large contiguous areas of conifer cover and to establish areas of low flammability with deciduous species such as aspen (Volney and Hirsch, 2005). Detailed reviews of adaptation options for forest management are available *(see* Sector Impacts and Adaptation chapter; Ogden and Innes, 2007, 2009; Gauthier et al., 2014).

4.4 Collaborative water management reduces negative impacts

Regional land-use policy and planning, as well as emergency preparedness, are critical for reducing the impacts of flooding and drought in the Prairie provinces. Collaboration is needed among all levels of government, and with stakeholders such as watershed stewardship groups, rural municipalities and conservation districts, to implement these adaptation measures and to promote practices that prevent or minimize adverse effects of water excesses and shortages.

The Prairie provinces have extensive experience dealing with water excesses and shortages, and have developed important mechanisms for adapting to climate variability. While many of these mechanisms are tailored to drought, some also address flooding and excessive moisture. The extensive management of water flows through dams, diversions and withdrawals on the Prairies makes it difficult to discern climate-related changes; adaptive management of water resources can help to compensate for changes in the availability of water supplies, while also reducing the impacts of flooding and drought.

4.4.1 Institutional mechanisms

Interprovincial level

Canada's decentralized approach to water governance provides the provinces with considerable autonomy over water-related decisions (Heinmiller, 2018). The Prairie Provinces Water Board (PPWB) is an enduring institution established in 1948 to foster water management cooperation among the provinces of Alberta, Saskatchewan and Manitoba. The Master Agreement on Apportionment (MAA) was created by the PPWB in 1969 (Heinmiller, 2018) and states that in any given year, each province is entitled to half of the natural flows of interprovincial rivers, as measured at the provincial boundary (Prairie Provinces Water Board, 2015). The MAA thereby removes potential uncertainties associated with interprovincial politics when dealing with water scarcity. It provides water managers in each province with a clear quota of the amount of available water that they will manage, even if the actual amount of water in the river is uncertain or highly variable.

While the PPWB and MAA provide this important mechanism to address hydroclimate extremes, particularly drought, they can also be inflexible under changing climate conditions, given the strictly defined apportionment of surface water among the Prairie Provinces. The PPWB has been examining the issue of the MAA's resilience under various climate scenarios (Prairie Provinces Water Board, 2014). This type of strategic exercise demonstrates one benefit of the PPWB and the interprovincial governance networks that it fosters.

Provincial level

The individual Prairie provinces have differing approaches to coping with hydroclimatic extremes. For example, Alberta uses a cap-and-trade system for reallocating water licences during times of water scarcity, whereas Saskatchewan and Manitoba take a more centralized approach with strong government oversight (Heinmiller, 2018; Government of Manitoba, 2018). Alberta allows for the creation of water markets at the regional level to reallocate water from low-valued to high-valued uses when drought threatens the status quo. While this is a potentially useful institutional mechanism, concerns have been raised about fairness and equity issues that could emerge (Hurlbert and Gupta, 2017). For example, declining summer river flows from the Rocky Mountains could affect water allocations in southern Alberta, especially for junior licence holders, since the major irrigation districts hold the senior licences. The effect of low water levels in the South Saskatchewan River Basin (SSRB) was ameliorated somewhat following the drought of 2001–2002, when the transfer of water rights was introduced and the Government of Alberta closed much of the SSRB to new surface water allocations (Government of Alberta, 2006). Saskatchewan's more centralized approach may limit opportunities among affected stakeholders for sharing and learning about drought response mechanisms and other adaptation challenges (Hurlbert and Gupta, 2017).

The previous experiences of the Prairie provinces with water and weather extremes have led to the development of important mechanisms for adapting to climate variability. All three provinces have a plan for drought—the region's worst threat *(see* Table 4.3)—, and Alberta's plan also addresses the risks of excessive moisture, demonstrating how some mechanisms tailored to drought could be repurposed to address concerns about flooding and excessive moisture. The Saskatchewan plan is mostly focused on agricultural risks, as drought planning is part of the Water Security Agency's broader mandate and 25-year plan.

Manitoba's drought planning appears to recognize the wider environmental, economic and societal impacts. All of the plans consider climate change to some extent.

Table 4.3: Provincial drought planning: Some characteristics and status

PROVINCE	MOST RECENT REPORT	LEAD MINISTRY/ MINISTRIES	CLIMATE CHANGE ADDRESSED?	NEXT STEPS? (EXAMPLES)	CURRENT IMPLEMENTATION STAGE? (EXAMPLES)
Alberta	Alberta's Agriculture Drought and Excess Moisture Risk Management Plan (2016)	Alberta Agriculture and Forestry	Yes	Continued improvement is envisioned	Drought and excess moisture advisory group
Saskatchewan	25 Year Saskatchewan Water Security Plan (2012)*	Ministry of Agriculture; Water Security Agency	Yes	Several listed (e.g., coordination of moisture monitoring, new infrastructure)	Moisture monitoring committee meets as needed
Manitoba	A Made-in-Manitoba Climate and Green Plan (2017)	Manitoba Sustainable Development and Stewardship (now the Ministry of Conservation and Climate)	Yes	Evaluate the strategy and update; determine drought preparedness levels	Evaluate and update the strategy; status of action items are reported (2017)

** The plan includes drought response actions.*

Watershed or regional level

Across the Prairie provinces, watershed-based organizations have become an effective mechanism for local climate change adaptation planning and soil water protection. In Manitoba, the Watershed Districts Program (formerly Conservation District Program) is a partnership between the province, which provides most of the funding, and more than 130 municipalities that develop and administer soil and water conservation programs. The Watershed Districts Act, proclaimed on January 1, 2020, transitioned 18 conservation districts to 14 new watershed districts, with boundaries based on drainage divides (Government of Manitoba, 2020). Integrated watershed management plans were among 30 municipal planning documents reviewed in a report commissioned by Manitoba Sustainable Development (now the Ministry of Conservation and Climate) (International Institute for Sustainable Development, 2019). Only five of the 30 documents explicitly referred to the need to adapt to climate change, and none included climate projections, nor committed to taking further actions to assess the climate change risks to their communities. Saskatchewan established local Watershed Stewardship Groups to work in collaboration with the provincial government to address a broad range of water quality-related issues. These groups constitute forums for multiple stakeholders to discuss local water issues and design locally appropriate solutions. They typically include participants from municipalities, agricultural producers, environmental NGOS and other industries in the respective watershed. While initially focusing on water quality, these groups have since branched out to tackle other water-related issues, including drought and flooding (Pittman et al., 2016). Many groups have been involved in climate change adaptation projects, including the development of extreme hydroclimate scenarios and action plans to provide watershed-specific solutions (Pittman et al., 2016). In Alberta, eleven Watershed Planning and Advisory Councils (WPACs) are independent, non-profit organizations designated by Alberta Environment and Parks to report on the health of their watersheds, lead collaborative planning, and facilitate education and stewardship activities. Each WPAC engages key stakeholders in their watershed, seeking consensus on land and water management strategies to achieve shared environmental, social and economic goals *(see* Case Story 4.3).

Case Story 4.3: Collaborative adaptation planning in Alberta watersheds

With Alberta's long history of great variability in river flow volumes and recent experience with flood and drought, water experts, managers and users across the province have recognized the importance of collaborative and proactive adaptation planning. Since 2010, a series of projects have brought together municipalities, industry, government, watershed groups, environmental groups, Indigenous groups and academics to explore the implications of climate change for water supplies and to develop strategies to support sustainable and resilient water management. Working groups have developed and used interactive water balance models to simulate flows and operations based on historic records and future climate change scenarios (Sauchyn et al., 2016).

The Bow River Basin (BRB) Working Group considered the alternative use of reservoirs to augment low river flows and improve ecosystem health. Reservoirs are often filled during low-flow periods in the late summer, coinciding with warm air temperatures; these two factors together strain both the quantity and the quality of water in downstream rivers. One potential adaptive strategy is the use of a "water bank", which would hold a specific amount of water in the upper BRB reservoirs to be released as dictated by low flow conditions downstream. Following severe flooding in 2013, the working group examined options for using existing and new reservoirs in the upper Bow River system to reduce peak flood flows through urban and rural communities *(see* Figure 4.8). The resulting report put forward 12 recommendations, including feasibility studies for three potential flood mitigation structures and for a series of smaller projects to maintain a balance between flood and drought resilience (Bow River Water Management Project, 2017).

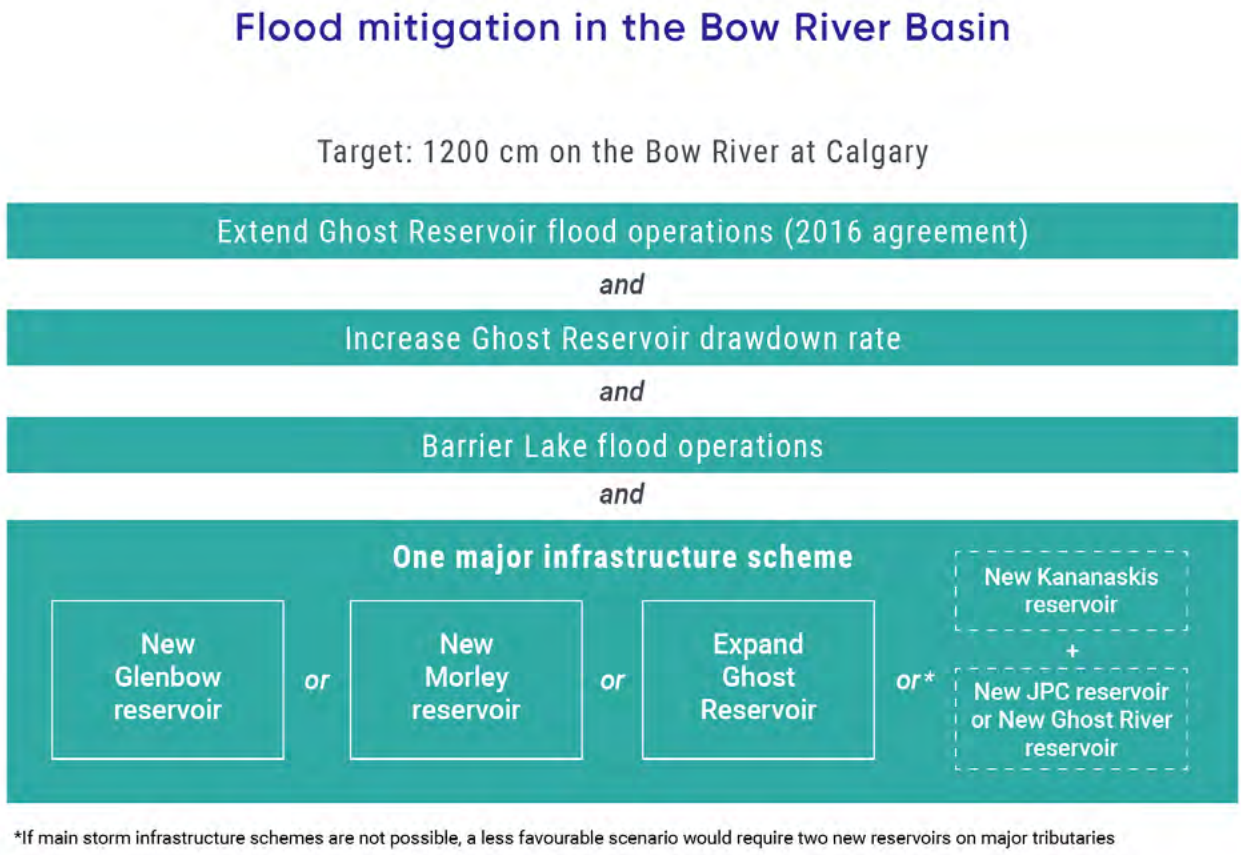

Figure 4.8: Approaches considered by the Bow River Basin Working Group for reducing flood impacts. Source: Bow River Water Management Project, 2017.

The Athabasca River Basin (ARB) Working Group linked a physically-based hydrological model of the watershed to data on water use and allocations to better understand the role of land-use policy and practices in adapting to changing water supply and demand. The working group followed a structured process *(see*

Figure 4.9) that identified 12 broad strategies and six recommendations to support sustainable water management into the future (WaterSMART Solutions Ltd., 2018). These recommendations included land-use planning to maintain natural hydrological functions, sharing and applying Indigenous knowledge, and establishing environmental flow needs.

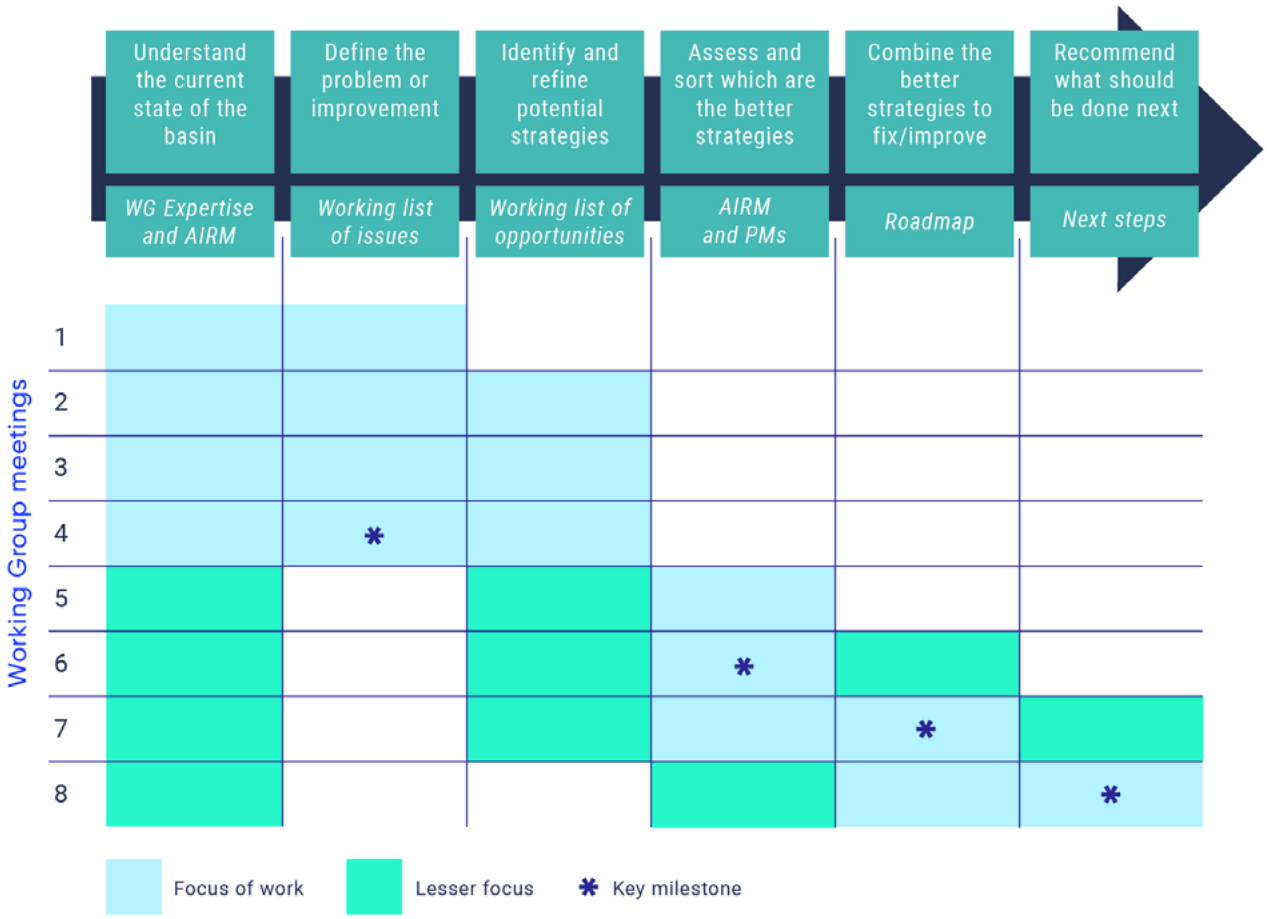

Figure 4.9: The process used by the Athabasca River Basin Working Group to move from increasing understanding of the Athabasca River basin to developing a roadmap for sustainable water management (AIRM: Athabasca Integrated River Model; PM: Performance Measures). Source: WaterSMART Solutions Ltd., 2018.

Both collaborative projects supported institutional resilience in Alberta by bringing together water managers and stakeholders to build a common understanding of climate change impacts on the balance between basin water supply and demand. Participants were able to identify and test adaptation strategies and scenarios, and collectively identify practical options to increase resilience in the watershed.

Irrigation districts across the Prairie provinces are another type of local stakeholder group that helps to manage hydroclimate extremes. While initially developed to manage local water for irrigation, they are now engaged in a broader range of issues. For example, during the 2001-2002 drought, the water markets referred to previously were coordinated by the local irrigation district in the Oldman River Basin of Alberta. Irrigation districts provide a locally-rooted mechanism for building trust and fostering collective action in the face of water-related adversity. They have been involved in participatory scenario exercises to prepare for drought (Hadarits et al., 2017) and have also voluntarily taken on new roles addressing adaptation to excessive moisture. The infrastructure managed by the irrigation districts to enhance agricultural production has also proven useful in recent years for dealing with excessively wet conditions (Hadarits et al., 2017).

4.5 Climate change brings both benefits and threats to agriculture

Prairie agriculture, particularly crop production, may benefit from higher temperatures and a longer growing season. Achieving net benefits will require adaptation to limit the impacts of climate extremes, including on water availability, and the increased risk of pests, vector-borne diseases and invasive species. Although agricultural producers are highly adaptable to fluctuations in weather and climate, barriers to adaptation include limited information and awareness of climate change impacts, combined with limited financial resources and institutional support.

Agriculture is a key employer and a major driver of the economy in the Prairies. Climate change brings both opportunities for and threats to agriculture. Direct impacts include changes in growing season length, timing and quantity of precipitation, heat units, extreme events—such as heat, hail and windstorms, flooding and drought. Indirect climate change impacts include effects on weeds, diseases, insects and soil characteristics, as well as on socio-economic factors influenced by global-scale changes in climate. These factors include effects on global food security, and trade and relations with supply industries for agricultural production and food processing. Assessing the convergence of these direct and indirect impacts is a major challenge. The overall impacts of climate change will depend on the effectiveness of adaptation not only in the Prairie provinces, but in Canada more generally and in other countries as well.

4.5.1 Impacts

Climate change has both direct and indirect impacts on agriculture in the Prairie provinces, resulting in both risks and opportunities (Kulshreshtha and Wheaton, 2013). Changing precipitation, temperatures, carbon dioxide levels and other variables will affect the following: crop and pasture productivity, quality and nutrient cycling; weeds, insects and diseases; and livestock production and reproductive rates (Sudmeyer et al., 2016). Projected biophysical impacts include increased water scarcity, more frequent extreme precipitation events,

shifting and variable precipitation patterns, longer growing seasons, increasing heat units (i.e., a measure of crop development in relation to temperature), and more frequent and intense droughts (e.g., Bonsal et al., 2019; Kulshreshtha and Wheaton, 2013).

Certain crop yields and hay productivity may increase in the near term in response to climate factors, such as longer growing seasons and increased heat units *(see* Box 4.3). However, high temperatures, droughts and more variable precipitation negatively affect crop yields, particularly for canola and wheat (Meng et al., 2017; Qian et al., 2018). Increased exposure to high temperatures (e.g., over 30°C), especially at critical times, may also reduce yields of corn, soybean, canola and wheat (Schauberger et al., 2017; Meng et al., 2017).

Box 4.3: Climate change impacts on future crop yields

Much of the historical variation in annual crop yields is attributable to climatic variability (Qian et al., 2009; Wittrock et al., 2014). For example, in Saskatchewan's Swift Current River Basin, the water balance index and the departure of spring wheat yields from expected values have a strong correlation with negative anomalies in drought years and higher than expected yields in years with positive water balances *(see* Figure 4.10; Wittrock et al., 2014). Yields have generally increased over time thanks to improved management and new technology. The yield data were detrended to remove the influence of farming practices, so that the effects of climate variability are the primary focus. However, technology advances are important adaptation measures that continue to improve agricultural production.

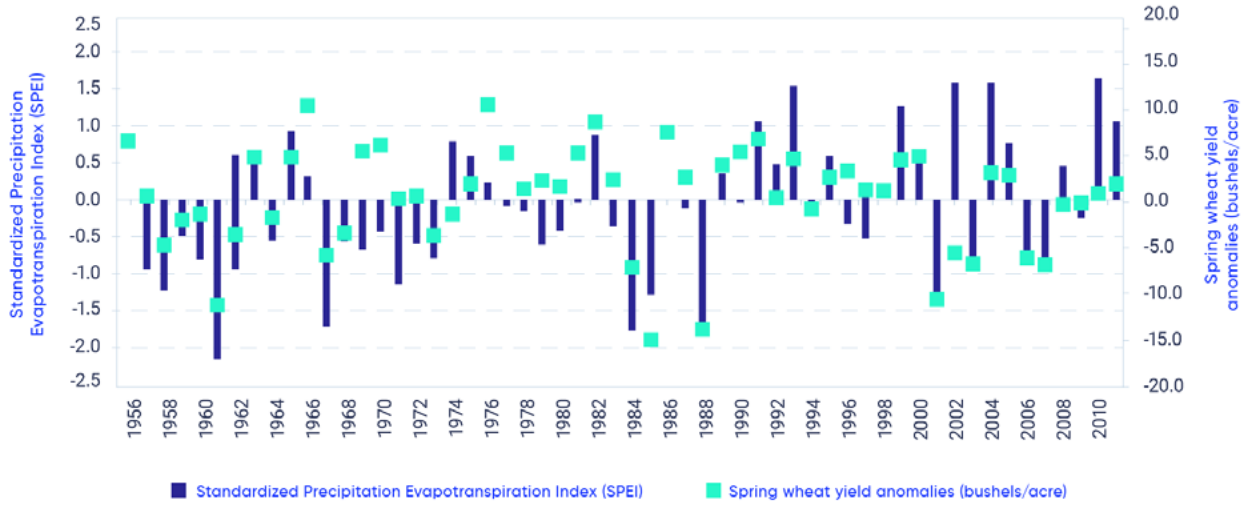

Figure 4.10: Comparison between spring wheat yield anomalies (e.g., departures from the trend) and growing season Standardized Precipitation Evapotranspiration Index (SPEI) for the Swift Current Creek Watershed in Saskatchewan. Source: Wittrock et al., 2014.

Projections of changes in crop yields in the Prairie provinces are limited, uncertain and largely only available for a few main crops *(see* Table 4.4). Spring wheat yields are projected to increase by 8–37% and higher by the 2050s under medium and high emissions scenarios (He et al., 2018; Qian et al., 2015, 2016; Smith et al., 2013). A large proportion of this increase is due to the direct effect of increasing carbon dioxide levels. For example, increases in the simulated average wheat yield range from 26% to 37% of the baseline yield when the effects of elevated carbon dioxide are included, but reach only 15% when carbon dioxide effects are excluded (Qian et al., 2016). Estimates for other main crops are limited. Increased heat and water stress on current crop cultivars may reduce canola yields (Qian et al., 2018). Examples of agriculture-specific adaptations include irrigation, use of cultivars with greater tolerance to heat and drought stress, and earlier seeding dates and fertilization (e.g., Qian et al., 2016). Some of these adaptation strategies were considered in the model simulations referred to in Table 4.4. Information and support from agriculture ministries, the agricultural industry and producer groups will help to enable crop producers to adapt to climate change, thereby ensuring that these simulated yield increases are practical and attainable.

Table 4.4: Simulations of changes in future crop yields in the Canadian Prairies (Qian, 2018)

LOCATIONS	CROP	YIELD CHANGE AND TIME PERIOD	CLIMATE SCENARIO	CROP MODEL	REFERENCE
Swift Current, SK	Spring wheat	8–11% (2041–2070) 8–15% (2071–2100)	CanRCM4 RCP4.5 and RCP8.5	DSSAT	He et al., 2018
Brandon, MB	Canola	-21% to -44% (2041–2070) -23% to -74% (2071–2100)	CanRCM4 RCP4.5 and RCP8.5	DSSAT	Qian et al., 2018
13 locations across the Prairies	Spring wheat	15–25% (2041–2070)	CanESM2 and CanRCM4 RCP4.5 and RCP8.5	DSSAT	Qian et al., 2016
11 locations across the Prairies	Spring wheat	26–37% (2041–2070)	CGCM3 and HadCM3 IPCC SRES A2	DSSAT	Qian et al., 2015

LOCATIONS	CROP	YIELD CHANGE AND TIME PERIOD	CLIMATE SCENARIO	CROP MODEL	REFERENCE
Dauphin, MB; Melfort, SK; Edmonton, AB; Fort Vermilion, AB	Timothy	>24% for first cut and <-31% for second cut (2040–2069)	CGCM3 and HadGEM1 SRES A1B and A2	CATIMO	Jing et al., 2013
Swift Current, SK	Spring wheat (Biofuel cultivar)	41–74% (2040–2069)	CGCM3 SRES A1B, A2, B1	DSSAT	Wang et al., 2012
Swift Current, SK; Melfort, SK; Lethbridge, AB	Spring wheat	~37% (2040–2069)	CCGCM3 SRES A1B A2, B1	DNDC	Smith et al., 2013

Extreme events, particularly droughts, negatively affect crops, livestock and forage production, causing financial losses such as those that occurred in 2001–2002, when drought resulted in a more than $2.97 billion reduction in agricultural production in the three Prairie provinces (Wheaton et al., 2008). Such impacts require further assessment and documentation (Craft et al., 2017), including an examination of the social aspects *(see* Section 4.6). Climate change extremes also affect soil and water quality through increased risk of soil erosion, soil salinization, desertification and soil degradation (Wheaton and Kulshreshtha, 2017). For example, flooding of agricultural lands due to precipitation extremes caused $1 billion in damages in the southeastern Prairies in 2014 (Szeto et al., 2014) and almost $700 million in 2011 in Manitoba alone (Public Safety Canada, 2019).

Future surface and soil water deficits (Bonsal et al., 2019) will have profound effects on the quantity and quality of surface water and on groundwater supplies. Decreased availability of river water is a concern for all producers, particularly those irrigating crops. Plant germination and reproduction are highly sensitive to moisture and heat stress corresponding with the timing for these stages in the life cycle of plants (Champagne et al., 2012). Negative impacts on water quality also result from extreme rainfall events, generating runoff with heavy nutrient loads, and from longer periods of low flow in streams and rivers (Venema et al., 2010).

4.5.2 Adaptation

While agricultural producers can benefit from longer and warmer growing seasons and increasing carbon dioxide levels, other climate change impacts, such as water scarcity, and excess moisture and heat, may be very challenging. Existing adaptive practices include the use of zero-till agriculture, feed stockpiling, increasing farm size, beneficial management practices, insurance, large-scale infrastructure such as dams (e.g., Smit and Skinner, 2002; McMartin and Hernani Merino, 2014; Warren, 2016a), earlier seeding dates, mixed farming and changes in crop varieties. Beneficial management practices include the use of methods, policies, programs and tools for improving the environmental and economic positioning of agriculture (McMartin and Hernani Merino, 2014). Unexpected social, economic and environmental consequences of adaptive practices could render some strategies maladaptive, meaning that despite attempting to reduce risk to climate change, they inadvertently increase vulnerability (Müller et al., 2017).

Agricultural systems need to adapt to a suite of climate change impacts that interact with other factors, such as economic pressures, opportunities related to an increasing global population, changing human dietary preferences, increased input costs and energy prices, competing land-use pressures and policy-related economic pressures. Agricultural producers have access to various types of adaptation options, ranging from relatively minor measures, such as growing drought-tolerant crop varieties, to more substantial or even transformative changes (i.e., major, purposeful actions at the farm level or higher), such as policies that remove obstacles to climate change adaptation or changes from dryland cropping to irrigation (Rickards and Howden, 2012). However, the cumulative impacts associated with multiple drivers of change will test overall capacity to adapt. Economics is a major motivation in the adoption of new practices *(see* Sector Impacts and Adaptation chapter), and the most appropriate adaptation measures will depend on a large number of factors, including capacity *(see* Case Story 4.4).

Case Story 4.4: Building adaptive capacity in Indigenous communities through agriculture

Although farming operations in any given region will likely experience similar biophysical climate change impacts, differences in vulnerability and adaptive capacity may result in very different experiences, especially between Indigenous and non-Indigenous communities. Social factors such as culture, socio-economic status and historical experience with agriculture will influence how farmers adapt. Factors such as the low socio-economic status in many First Nations communities exacerbate vulnerability and negatively affect resilience to climate extremes. While federal legislation has historically inhibited many First Nations from participating in agriculture (Tang, 2003), today there are several examples of successful agricultural initiatives undertaken by First Nations in the Prairie region. Examples include the Blood Tribe Agricultural Producers in southern Alberta (Kulshreshtha et al., 2011), whose operations are vulnerable to periodic flooding (Magzul, 2009) and the Muskoday First Nation in Saskatchewan, which has operated a successful organic agriculture co-operative for over a decade (Martens, 2016). The use by First Nations of alternative agricultural practices (e.g., organics) may have higher resilience in terms of ecological and market diversity, and could include the

harvesting of native plants and traditional foods. Two consultation sessions between the federal government and First Nations representatives in Alberta and Quebec revealed obstacles and opportunities facing the participation of First Nations in agriculture (Agriculture and Agri-Food Canada, 2017). Access to capital, support programs and extension services (e.g., mentoring, information sharing) were identified as needs. While climate change adaptation was not mentioned explicitly in the consultation report (Agriculture and Agri-Food Canada, 2017), access to related resources could enhance the participation of First Nations in agriculture, thereby enhancing their adaptive capacity.

Mixed farms with both crops and livestock have advantages for adaptation. Drought response practices for mixed farms may include purchasing feed when necessary and early weaning of calves, combined with feeding strategies aimed at reducing both feed demand and the producer's financial burden during drought periods (Poudel and Kulshreshtha, 2016; Poudel et al., 2017). Options that are more specific to rangeland and livestock production include herd management, raising alternative breeds and species, pest management, and changes in enterprises and geographic locations (Joyce et al., 2013).

Current barriers to adaptation include a lack of awareness of options, inadequate financial resources and institutional support mechanisms, insufficient preparation, and political resistance (e.g., Lilliston, 2018). The development of irrigated areas—a logical adaptation to increased water stress in agricultural systems—involves building dams and distribution channels, and is therefore highly capital intensive (Warren, 2016a). Water availability for irrigation may also be a limitation, as stream flows are reduced during severe droughts *(see* Section 4.4; Wheaton et al., 2008). Existing irrigation systems may not be able to cope with the water demands of a multi-year drought. Observed trends toward increasing farm debt (Statistics Canada, 2017b) may severely impede the ability to undertake adaptive actions.

Increases in heat units and longer growing seasons will affect agronomic management practices such as seeding dates. Heat stress may result in a shorter growing season for some crops, such as soybeans (Jing et al., 2017). For crops like canola, earlier seeding and increased fertilization are limited options because of increased heat and water stresses, which are important limiting factors for crop yields. Key adaptation measures include new heat- and drought-tolerant cultivars (Qian et al., 2018). Higher temperatures could lessen the limitations imposed by a short growing season along the northern margins of the agricultural zone. However, extending agriculture into this region will require adaptation of farming practices to yield crops in nutrient-poor forest soils.

Governance institutions play important roles in adaptation and can improve the adaptive capacity of producers and other rural residents (Hurlbert et al., 2009). However, capacity constraints and isolation exacerbate the vulnerability of many rural communities (Hanna, 2011; Lal et al., 2011; Garschagen, 2013). Institutions that deal with water management and development, including the former Prairie Farm Rehabilitation Administration, water-user groups, watershed stewards and irrigation project associations (Marchildon, 2009; McLeman et al., 2014; Hurlbert and Gupta, 2017) are instrumental in facilitating adaptation actions *(see* Section 4.4.1).

Farmers have relied on their understanding of local climate regimes to manage risk, and may not consider alternative farming practices without evidence of economic benefits (Heal and Millner, 2014; Convery and Wagner, 2015; Yusa et al., 2015; Wood et al., 2016). While the impacts of drought have been the subject of previous studies, impact assessments of flood, extreme heat and winter thaw events are more limited.

4.6 Social groups have unique vulnerabilities and strengths

The impacts of climate c hange may exacerbate existing societal inequities, especially among Indigenous peoples, women, people of low socio-economic status, youth and the elderly. Public policy and adaptation planning should consider the unique vulnerabilities and strengths of these social groups, and also the means by which race, age, gender and poverty amplify vulnerability or resilience to climate hazards.

Climate impacts interact with existing social inequalities, which are influenced by histories of oppression and/or colonization affecting different groups of people in different ways. Indigenous peoples, people of low socio-economic status, ethnic minorities, youth and elders all have unique strengths and vulnerabilities when adapting to climate change. Social inequality shapes social roles, access to resources and decision-making power. Multiple forms of inequality can intersect to create different experiences, even within certain groups; this is known as intersectionality. Social inequality and marginalization also shape people's access to social infrastructure, such as services and facilities, and to physical infrastructure; this in turn affects their ability to cope with and adapt to climate change. By considering these interrelated social factors, we can plan for climate hazards more effectively and ensure that responses and infrastructure are inclusive and beneficial for all.

4.6.1 Introduction

Climate change impacts will have widely divergent effects on Prairie economies and communities. The capacity to adapt to these impacts also varies widely. Although reliance on natural resources remains important for the economies of all three provinces, the business and service sectors are also important. The Prairie population is increasingly urbanized (Statistics Canada 2011b), with a small number of medium and large cities, combined with numerous rural communities of relatively low, and in many cases, ageing populations that are reliant on climate-sensitive sectors such as agriculture, forestry and tourism *(see* Rural and Remote Communities chapter).

The following analysis combines information available on the status of vulnerable social groups in the Prairie provinces. Due to limited data on how climate change affects vulnerable groups in the Prairies specifically, this section also presents a broader review of the literature on climate impacts and adaptation by drawing on

research conducted in other regions. It also benefits from new conceptual frameworks that provide insights into understanding vulnerability *(see* Box 4.4).

Box 4.4: Understanding vulnerability

Technical approaches to vulnerability assessment tend to employ common metrics of exposure, sensitivity and adaptive capacity, and to characterize large groups of people as collectively experiencing the same forms of vulnerability. This approach has several limitations, including the inappropriate categorization of groups as equally vulnerable and as passive victims (Arora-Jonsson, 2011; Cameron, 2012), an inability to accommodate cultural understandings of values, risk (Adger et al., 2012; Wolf et al., 2013; Reid et al., 2014), local knowledge and other context-specific features of social systems (Adger et al., 2012; Ford, 2012), and the exclusion of certain sources of inequality and oppression (Iniesta-Arandia et al., 2016), such as colonialism (Cameron, 2012). Some of these limitations can be overcome through the inclusion of intersectionality and social infrastructure approaches, which help to identify not only intersecting sources of vulnerability, but also unique adaptive capacities among marginalized groups.

Intersectionality

An intersectionality approach considers how multiple attributes and identities can intersect to affect vulnerability and adaptive capacity (Kaijser and Kronsell, 2014; Moosa and Tuana, 2014; Iniesta-Arandia et al., 2016). It acknowledges that individuals' experiences of climate change are shaped by power systems that intersect with the ability to empower or marginalize people based on sex/gender, race, socio-economic status, age, location, sexual identity and other factors. For example, although there are gendered trends in the experience of climate extremes, not all women will experience an extreme in the same way because gender combines with other factors, such as high/low income or Indigeneity, to create different experiences amongst women. In climate change research, intersectionality is useful in acknowledging that: (a) group vulnerability to climate change is a product of social relations that include power and privilege, and it is not inherent or immutable; and (b) not all members of a group will have the same experience, as a result of inter-group differences and contexts. This approach also recognizes agency, including contributions and insights that stem from marginalized perspectives, such as Indigenous knowledge and women's experiences.

Social infrastructure

The concept of social infrastructure refers to the collective capabilities of institutions, communities or organizations to provide or take advantage of opportunities that enhance their economic and social well-being. Social infrastructure encompasses "the social environment [facilities and infrastructure], services and programs that support the accumulation and enhancement of human capital" and quality of life, including the sense of belonging that is fundamental to healthy and sustainable communities (Teriman and Yigitcanlar, 2011). Focusing on social infrastructure can draw attention to existing practices, and whether or how they can be retained or revised for positive adaptation to climate change.

4.6.2 Vulnerable social groups

While there is value in understanding which factors render various social groups (e.g., women, Indigenous people) more or less vulnerable to climate change, it is important to avoid portraying all members of such groups as inherently and consistently vulnerable and lacking the ability to respond to risks (e.g., Arora-Jonsson, 2011; O'Shaughnessy and Krogman, 2011; Cameron, 2012; Moosa and Tuana, 2014). The main elements of these vulnerabilities are described below, noting that unique strengths can advance adaptation action.

Indigenous peoples

Many Indigenous peoples are disproportionately exposed to the impacts of climate change (Parlee and Furgal, 2012). Furthermore, Indigenous peoples experience significantly higher rates of poverty and unemployment, and lower average rates of income than the non-Indigenous population *(see* Table 4.5), while having less access to many services. Table 4.5 demonstrates income inequality at the intersection of gender and Indigeneity, showing notable income differentials not only between Indigenous women and non-Indigenous women, but also between Indigenous women and Indigenous men. Research on Indigenous vulnerability to climate change in the Prairies (Wittrock et al., 2011; Christianson et al., 2012; Mottershead, 2017; Patrick, 2018a,b) has identified how these and other interacting social factors exacerbate the impacts of climate change and compromise adaptation. Importantly, however, Indigenous communities are also leading their own climate change studies—for example, through federal programs such as the First Nation Adapt Program and the Indigenous Community-Based Climate Monitoring Program, among others.

Table 4.5: Selected socio-economic metrics for Indigenous and non-Indigenous populations in the Prairie provinces and Canada

GROUP	CANADA	SK	AB	MB
Median annual after-tax individual income, 2016				
Male, non-Aboriginal	$36,267	$42,483	$47,723	$36,826
Female, non-Aboriginal	$26,811	$30,528	$30,903	$27,430
Male, Aboriginal	$26,507	$22,297	$34,122	$22,673
Female, Aboriginal	$22,799	$23,231	$24,414	$22,206
Unemployment rate, 2018				
Aboriginal population over 15, all education levels	10.1%	11.5%		

Non-Aboriginal population over 15, all education levels	5.7%	6.1%

SOURCES: STATISTICS CANADA DATA TABLES #98-400-X2016171 AND #14-10-0359-0

Note: Census data still refers to "indigenous" peoples as "aboriginal"

Existing Canadian studies have shown that legacies of historic colonialism and its persistence today manifest in numerous ways, from poverty and poor living conditions, to substance abuse (Cameron, 2012; Veland et al., 2013; Williams, 2018). These conditions multiply the effects of risk, with particular implications for health status (Ford et al., 2010), and can result in reduced coping capacities during extreme events (Mottershead, 2017). The effects of the 2013 flood in the Siksika First Nation reserve in Alberta were more severe than in other communities, with one quarter of residents evacuated, 134 homes destroyed (which constituted approximately 9% of all homes in the Nation, according to 2011 Census figures), and loss of water supply to 62% of the remaining homes, despite which they were forced to wait longer than residents in other regions for recovery assistance (Patrick, 2018a). Studies of the severe flooding experienced in 2011 in the Lake St. Martin community and nearby First Nations communities in Manitoba highlight a lack of warning, forced evacuation on short notice, inadequate recovery efforts (some families remained displaced at the time of this chapter being written) and consistent lack of communication between emergency agencies and residents (e.g., Martin et al., 2017; Thompson, 2015).

Indigenous peoples rely to a greater—though varying—extent on local foods, with the result that shifts in availability of and access to those sources can directly affect food security and livelihoods. Limitations on the ability to participate in traditional land-based activities because of changes in species distributions and wildfires, as well as non-climate factors, can also affect mental well-being and can increase dependence on the cash-based economy (Bunce et al., 2016).

Treaty rights and other regulations may restrict Indigenous peoples' access to their territories and/or constrain land-based adaptation strategies by specifying the types of activities in which Indigenous peoples can and cannot engage (Wittrock et al., 2011; Natcher et al., 2016; McNeeley et al., 2018). In addition, the remote location of some communities translates into acute risk to extreme events, such as floods and wildfires (Christianson et al., 2012), which can be exacerbated due to lack of early warning systems (Ford et al., 2010), and transportation networks (Tam et al., 2013) that are compromised or non-redundant (i.e., lacking alternative routes). For many communities in Northern Manitoba, for instance, mobility in winter via ice roads is jeopardized by a warming climate (Blair and Sauchyn, 2010; Taylor and Parry, 2014).

Research in regions outside of the Prairie provinces has found that food-sharing networks and other local institutions in Indigenous communities serve as important contributors to adaptive capacity (Baggio et al., 2016; Ready, 2018). Compromises in traditional sharing practices as a result of increased involvement in wage labour, for example, can affect food security to an even greater extent than declines in the availability of traditional foodstuffs (Baggio et al., 2016). Indigenous community residents living in their traditional homes also express high levels of place attachment, which can foster commitment to adaptation (Cunsolo Willox et al., 2012). However, this attachment to place may also interact with the acute personal and cultural consequences of both climate and non-climate impacts, affecting their ability to engage with the local

landscape (Cunsolo Willox et al., 2012) or resulting in their forced relocation.

Indigenous peoples also have several unique sources of adaptive capacity. Culturally appropriate forms of community inclusion in adaptation planning, specifically those including women and youth (Pennesi et al., 2012; Reid et al., 2014; Whyte, 2014), allow for the identification and prioritization of locally determined values (Christianson et al., 2012; Veland et al., 2013). Indigenous knowledge is of tremendous value to climate science and adaptation planning (Ingty, 2017; Rosales and Chapman, 2015; Reid et al., 2014; Ignatowski and Rosales, 2013; Veland et al., 2013; Leonard et al., 2013; Pennesi et al., 2012; Downing and Cuerrier, 2011). It encompasses detailed local and historical observations of changes associated with climate (Chisholm Hatfield et al., 2018) and is noted for being more inclusive of social elements than is Western science (Ignatowski and Rosales, 2013). Many Indigenous peoples are accustomed and adaptive to environmental change, with Indigenous knowledge providing important perspectives on the relationship between human activity and the environment (*see* Video 4.2; Leonard et al., 2013; Veland et al., 2013). As noted in Section 4.7.2, Indigenous communities are actively building adaptation strategies based on Indigenous Knowledge systems.

Video 4.2: Elder Dave Courchene is a respected Knowledge Keeper of the Anishinaabe Nation and founder of the Turtle Lodge. In this video, he shares his views on climate change, stewardship and Indigenous wisdom. Source: The Turtle Lodge and Prairie Climate Centre, 2017. https://youtu.be/nMt5l9gpWTk

Women

While gender analysis of climate change vulnerability and adaptation has increased substantially over the

past decade, studies specific to the Prairie provinces remain limited. Existing literature from other contexts acknowledges that, in general, gender inequality produces different experiences of climate impacts between women and men (Jerneck, 2018). For example, women's vulnerability to climate change is affected by lower average incomes (Perkins, 2017); gendered divisions of labour—especially in natural resources contexts and rural communities (Alston, 2013; Reed et al., 2014; Vasseur et al., 2015; Fletcher and Knuttila, 2016); unequal access to or control over land, technology and information (Seager, 2014); cultural norms and gender ideologies (Alston and Whittenbury, 2013; Reed et al., 2014); and less decision-making power (2014; Vasseur et al., 2015; Fletcher and Knuttila, 2016; Pearse, 2017).

The intersection of gender roles and low socio-economic status, for example, may increase vulnerability for women. Income affects people's ability to cope and adapt to climate extremes. Women across Canada continue to experience a pay gap compared to men, partly attributable to women's disproportionate participation in part-time employment (Statistics Canada, 2018b), which itself is due in part to women's ongoing and disproportionate responsibility for caregiving and domestic work (Moyser and Burlock, 2018). Even among full-time workers, statistics show provincial pay gaps of 24.6% in Alberta, 21.6% in Saskatchewan and 13.2% in Manitoba (Conference Board of Canada, 2017). Another major factor influencing this pay gap is the occupational division of labour, in which sectors with a larger representation of women tend to have lower pay levels than male-dominated sectors (Vincent, 2013). Women are also less likely than men to be employed. The three Prairie provinces (plus Ontario) show the highest male-to-female employment gaps in Canada, with 11.3 percentage points for Alberta, 8.8 in Manitoba, and 8.2 in Saskatchewan (Statistics Canada, 2018b).

The percentage of women living in poverty across Canada is consistently higher than the percentage of men in poverty. Of low-wage earners in Alberta, 59.6% are female. In Saskatchewan, 16.9% of women over 65 are in the low-income category, compared to 11.1% of women in the 18–64 age category and 14.5% of men who are 65 and over (Statistics Canada, 2016). Single mothers, lesbian women, women with disabilities, Indigenous women, women of colour, and women who have been incarcerated often experience more severe financial challenges than other people living in Canada (The Women's Centre of Calgary, 2017). Transgender people may also experience additional barriers to finding paid work (Trans PULSE, 2011), which could increase their vulnerability. No literature exists on transgender people's experiences of climate change in the Prairie region; however, research is beginning to explore the challenges faced by lesbian, gay and transgender people experiencing climate disasters elsewhere (e.g., Balgos et al., 2012; Dominey-Howes et al., 2014; Gorman-Murray et al., 2017).

In the Prairie region, available research suggests that rigid gender roles in agriculture, forestry and other resource contexts create different experiences for women and men. Women in agriculture may have less influence over on-farm adaptation decisions, including the use of technologies like drought-resistant seed (Fletcher and Knuttila, 2016). In forestry, women and Indigenous people's low decision-making power over natural resource management may extend to adaptation strategies (Reed and Davidson, 2011; Reed et al., 2014). Although women are more likely to experience inequality, research in the Prairies (Fletcher and Knuttila, 2016) and elsewhere (e.g., Alston, 2012) has shown that men may experience particular physical and psychological risks due to expectations of masculinity during climate disasters.

The knowledge and capacities of women and other marginalized groups (Moosa and Tuana, 2014) can be valuable contributions to adaptation. Women often play an active, but overlooked role on farms, in

households and communities, and during disaster response. The particular roles played by women may give them a different level or type of environmental awareness from men (MacGregor, 2010; Bunce et al., 2016; Fletcher, 2017), yet they continue to be underrepresented in climate governance (MacGregor, 2010; Pearse, 2017; Williams, 2018).

Rural communities

The general trend of depopulation and urbanization in the Prairie provinces has resulted in reductions in available funding for rural municipalities (Canadian Rural Revitalization Foundation, 2015), and the significant growth in farm size over the past two decades (Statistics Canada, 2007, 2011a, 2017a) has resulted in reductions in social capital and local services that are key elements of adaptive capacity (McLeman, 2010; Desmarais et al., 2015). Dependence on declining water resources for agriculture increases the risk of water conflict between industrial (e.g., oil, gas and mining), agricultural and rural household users (Clark et al., 2017). Financial precarity is an additional vulnerability factor in agriculture (Patiño and Gauthier, 2009; Pittman et al., 2011; Wittrock et al., 2011; Fletcher and Knuttila, 2016), along with lack of institutional support, including federal divestment from drought infrastructure (Marchildon, 2009; Shuba et al., 2016); fragmented flood policy instruments and planning that fails to consider climate projections (Hurlbert, 2018); and volatile markets (O'Brien and Leichenko, 2000; Patiño and Gauthier, 2009; Diaz et al., 2016).

Despite these vulnerabilities, rural residents often have significant adaptive capacity. Rural residents may be more equipped to cope with extreme events than urban residents (McLeman, 2010), and a culture of innovation has helped Prairie farmers adapt to drought over the past century (Warren, 2016a). Strong social capital exists in many rural communities across the Prairies, including cultural norms of mutual assistance during crises (Shuba et al., 2016). As noted in Section 4.7.2, some rural municipalities are carrying out their own adaptation planning processes. Priorities in adaptation planning include participatory planning with increased stakeholder involvement (Lal et al., 2011; Hurlbert, 2018); stable, coherent and consistent policy regimes (Pittman et al., 2011; Hurlbert, 2018); and consideration of climate scenarios in future planning (Hurlbert, 2018).

Low-income families

Prairie residents living in poverty may be more sensitive to climate extremes as a result of insecure sources of employment, poor quality housing, lack of insurance, lack of financial resources for adaptation and lower representation in decision-making forums. The vulnerability and adaptive capacity of people living in poverty in the Prairies has not yet been the subject of research attention; however, information on poverty in the Prairie provinces can inform consideration of the vulnerability of this group to climate change. Youth, women, racialized and Indigenous people are more likely to hold low-wage, part-time and insecure jobs, accounting for a large proportion of the working poor. Standard poverty rates vary between 9–14% across the prairies, but a more informed measure is the prevalence of low incomes based on low-income measure after tax, which is 13.6% in Alberta, 18.1% in Saskatchewan and 20.7% in Manitoba (Statistics Canada, 2016).

Poverty tends to be concentrated in certain rural communities and also in inner cities, which in certain cases may be more exposed to climate-induced hazards than other regions; for example, when poor housing is associated with inner-city neighbourhoods or when economically depressed rural communities lack the capacity to maintain infrastructure. Lone parent families also make up a large proportion of this group,

particularly female-headed households. By extension, rates of child poverty are significantly higher than poverty rates for the population as a whole. The percentage of children living in poverty is 15.7% in Alberta (Edmonton Social Planning Council, 2017a), 24% in Saskatchewan (Hunter and Sanchez, 2017) and 27.5% in Manitoba (Campaign 2000, 2017). The elderly and people with pre-existing health conditions are especially susceptible to heat waves and other climate extremes (Rapaport et al., 2015), and those with lower incomes often have no access to air conditioners (Gronlund, 2014).

Recent immigrants

Recent immigrants are rarely studied in climate change research; however, they represent a significant number of residents in many Prairie communities and can be subject to multiple sources of vulnerability. The lack of resources and the language barriers faced by some immigrants can limit adaptive capacity (Burke et al., 2012). Seasonal migrant workers not only experience the vulnerabilities of the average migrant, but also the precarity of work in the agricultural sector under climate change. Refugees in particular may be suffering from trauma due to experiences in their native countries, and many are visible minorities who may be subject to racial discrimination; even children experience this range of effects (Oxman-Martinez et al., 2012). Many recent immigrants are unfamiliar with the sources of social support that may be available. Each of these factors enhances vulnerability to climate change, particularly extreme events.

This group is expected to grow, in part due to increases in out-migration in response to climate change impacts in other parts of the world *(see* International Dimensions chapter). Alberta, in particular, is becoming a preferred destination for immigrants, after Ontario and British Columbia, with landed immigrants currently making up 23.6% of the working population (Government of Alberta, 2018). In 2015, 16,739 immigrants and refugees settled in Edmonton, compared to 6,016 in 2005 (Edmonton Social Planning Council, 2017b).

4.6.3 Sources of social vulnerability

Consideration of vulnerability that focuses exclusively on exposure, sensitivity and adaptive capacity may perpetuate disempowerment rather than enabling capacity building (Veland et al., 2013). For example, depictions of Indigenous peoples as highly vulnerable may serve to reproduce the paternalistic relations reflected in colonialism (Klenk et al., 2013; Veland et al., 2013). GHG emissions reduction and adaptation strategies can reinforce Western, masculine and/or technocratic approaches and male-dominant economic sectors (Williams, 2018). For example, the dominant approach to climate change adaptation favours infrastructure and technological solutions, like dams and zero-till agriculture, over more socially integrative approaches that attend to structural inequalities, social vulnerabilities and institutional barriers (VandenBygaart, 2016; Zeitoun et al., 2016).

Intersectional analysis *(see* Box 4.4) draws attention to the fact that nearly 80% of single parents in Canada are female (Statistics Canada, 2015). When combined with the gender pay gap, the intersection of gender and single-parent status may also affect vulnerability and contribute to child poverty. Similarly, although older adults in general are more likely than other age categories to be low-income (Hunter, 2011), the incomes of older men (65 and over) are still 1.5 times that of older women (Statistics Canada, 2018b), and more than

30% of older women live alone compared to 16% of older men (Statistics Canada, 2018b). In the Prairie region, intersectional analysis reveals particular issues experienced by low-income Indigenous women living on reserve, as compared to their non-Indigenous, male, off-reserve counterparts: Indigenous women are more likely to be lone parents and less likely to be employed than men and non-Indigenous women; they are more likely to live in poor housing on reserve and are self-reporting worse health conditions than Indigenous men (Arriagada, 2016).

Individuals characterized by intersecting causes of vulnerability also have important knowledge to contribute to climate change adaptation because of their perspectives and experience (Whyte, 2014). Both Indigenous women and men may possess unique knowledge about the environment and climatic change (Dowsley et al., 2010), generated through their traditional gender roles and responsibilities. Indigenous women's roles as water protectors, for example, may provide insights into climate change (Whyte, 2014). Older individuals, including male and female Indigenous Elders, hold important knowledge that corroborates and expands upon scientific climate records. The knowledge and contributions of socially marginalized groups can provide crucial insight for more effective and inclusive climate change adaptation moving forward. Furthermore, socially equitable adaptation policies and processes can go beyond inclusion, reducing the root causes of vulnerability and potentially increasing equality over time.

4.7 Adaptation planning helps to reduce climate risks

Cities are at the forefront of adaptation and resilience planning in the Prairie provinces. Governments and businesses have begun to assess climate risks and develop adaptation strategies, but few sector-specific plans and policies consider future climate risks, leaving some firms, governments and sectors unprepared. Assessing the effectiveness of adaptation measures andmeaningful reporting of progress would help achieve climate-resilient communities and local economies.

Governments, industry, businesses, Indigenous communities and civil society across the Prairie provinces are slowly embracing adaptation planning. Leadership is particularly evident from municipalities in the region, while provincial governments are in the early stages. Governments and corporations have begun to assess and disclose climate risks facing public and private assets. Continuous improvement through the evaluation of progress is not common. Another limitation is the continued reliance on recent historic climate conditions for defining climate variability and extremes, rather than referring to future climate projections.

4.7.1 Introduction

Climate change considerations are increasingly included in planning and management processes in municipalities, governments and businesses with diverse operational and management objectives (EPCOR, 2017; TransAlta Corporation, 2018; City of Regina, 2018). Ongoing adaptation projects and initiatives include fostering engagement and raising awareness, research and planning, training and skills development, and infrastructure design and construction from a climate perspective (Zizzo, 2014; Austin, 2015; Bruised Head, 2018; Blackfeet Nation, 2018).

Saskatchewan and Manitoba have climate change plans that include adaptation, reducing GHG emissions and building climate resilience. Saskatchewan's climate change strategy (Government of Saskatchewan, 2017) emphasizes existing government practices (e.g., research to support the adoption of new crop varieties) and commits to new strategies to enhance climate resilience within the province (e.g., improving understanding of future climate trends). Manitoba's Climate and Green Plan (Manitoba Sustainable Development, 2017) is based on four pillars: climate, jobs, water and nature. Adaptation strategies in the plan focus on climate knowledge, sustainable climate-resilient communities and sustainable agriculture.

4.7.2 Community-based adaptation planning and action

Under provincial legislation, Alberta's two largest cities are required to develop climate change plans *(see* Case Story 4.5; Government of Alberta, 2018). Thirteen other municipalities in Alberta have adopted adaptation plans that were developed using the Climate Resilience Express process (Boyd et al., 2016). This streamlined adaptation planning process is based on a one-day workshop that explores climate risks to municipal assets and operations. Rather than presenting a detailed quantitative analysis, the high-level screening approach is meant to be simple and accessible to communities with limited capacity. The output is an action plan for communities that requires implementation, review and updates. The process has been used to produce plans for numerous cities, towns and counties.

Case Story 4.5: Adaptation planning in Edmonton and Calgary

To support their adaptation planning, the cities of Edmonton and Calgary commissioned a series of white papers on building a climate-resilient city in the Prairies (Venema et al., 2017). The papers focused on economics and finance, agriculture and food security, urban ecosystems, transformational adaptation, transportation infrastructure, water supply and sanitation systems, infrastructure for electricity, information and communication technology, the built environment, and disaster preparedness and emergency management. These papers helped to inform climate change plans developed by the two cities.

Calgary launched its Climate Program in 2017 to facilitate GHG emissions reduction and climate change adaptation by the city and its residents and businesses *(see* Figure 4.11; City of Calgary, 2018). Adaptation

initiatives include flood planning, water conservation efforts, waste management planning, urban forest management and parks planning to support biodiversity and ecological resilience, naturalization of urban landscapes, green building and low-impact development, and upgrading of wastewater treatment facilities.

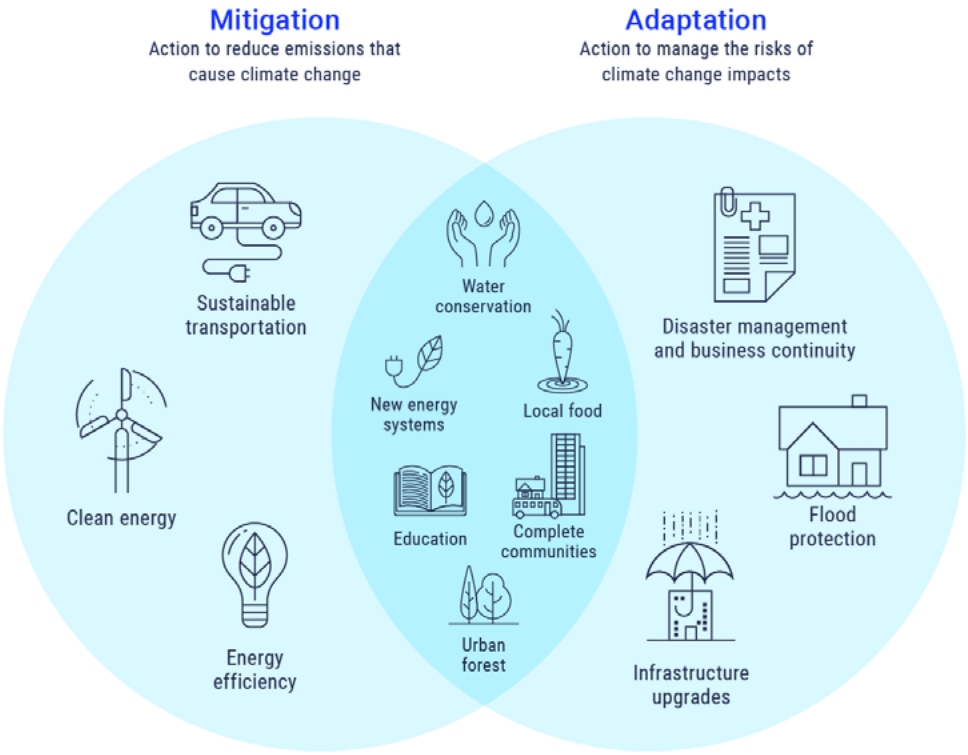

Figure 4.11: Considerations in building climate resilience in the City of Calgary. This figure has been used to build climate literacy with multiple stakeholders. Source: City of Calgary, 2018.

Calgary's Climate Resilience Plan (City of Calgary, 2018) describes what the city is doing to reduce GHG emissions and adapt to climate change. The plan identifies risks and vulnerabilities that city services and operations face as a result of extreme weather events and the business units responsible for implementing actions to reduce those risks. It is structured around five best practices for municipalities: government leadership; capacity building; integrated long-term climate planning; alignment with other initiatives (e.g., 100 Resilient Cities, 2020); and raising public awareness through education and outreach. In March 2018, the City began a series of Climate Change Symposiums to support a climate change conversation with Calgarians, community and youth leaders, entrepreneurs, climate experts and City staff.

The City of Edmonton took a phased approach to developing its climate change adaptation strategy (City of Edmonton, 2018a), starting with an assessment of risk under current climate conditions, examining climate change over the past century and projections of future change, and preparing an economic analysis of the costs of inaction and a review of case studies. A strategic climate change risk and vulnerability assessment

used quantitative models to identify physical damages and potential loss of services associated with a variety of climate impacts. Thematic stakeholder workshops involving over 100 participants were held to validate the risk analysis and prioritization. Graphic summaries from these workshops capture the participants' conversations and ideas (Hester, 2018).

Actions to manage climate risks were evaluated using five criteria: sustainability, effectiveness, risk and uncertainty, opportunity and implementation. They were also condensed into five potential pathways for managing risks, comprising science- and evidence-based decisions and preparatory actions for addressing changing temperatures, precipitation, weather extremes and ecosystems.

A summit of city mayors from around the world was held on March 6, 2018, and resulted in the Edmonton Declaration: a call-to-action for mayors to take leadership on climate change. Developed with input from the Federation of Canadian Municipalities, United Cities and Local Governments, C40 and ICLEI – Local Governments for Sustainability in advance of the IPCC Cities and Climate Change Science Conference, the Declaration commits local governments to undertake climate risk and vulnerability assessments to guide their planning and investment decisions, increase climate resilience and minimize the exposure of people and assets to the impacts of climate change (City of Edmonton, 2018b). It has been signed by over 3,000 cities globally. Edmonton's strategy has been designed to deliver on adaptation commitments from the Edmonton Declaration (City of Edmonton, 2018a).

The City of Saskatoon's Climate Action Plan, which includes its Corporate Climate Adaptation Strategy, was released in 2019 (City of Saskatoon, 2019). It undertook an engagement process—focus groups, surveys, pop-up community events and expert workshops—with local businesses, not-for-profit organizations, residents and subject matter experts to inform their Climate Change Business Mitigation Plan (Lura Consulting, 2018). Stakeholders identified climate change activities of interest and potential risks of concern, as well as potential benefits. Upfront costs, lack of infrastructure or services, and lack of responsibility and support were identified as the largest barriers to greater action.

The City of Selkirk, Manitoba, developed its climate change adaptation strategy by considering the seasonal impacts of climate change on municipal assets, local services, and human health and well-being, and by prioritizing risks and associated adaptation actions. Actions were ranked for their efficacy, and costs were calculated and integrated into the City's annual tactical budgeting process to support implementation. The City won the 2019 Tereo Award from the Canadian Network of Asset Managers in recognition of their innovative approach and commitment to climate action (City of Selkirk, 2019).

Indigenous communities in the Prairie provinces are also very active in adaptation planning (Crown-Indigenous Relations and Northern Affairs Canada, 2019). Common areas of focus among adaptation projects include food security and access to traditional foods, safety while on the land, water monitoring, and physical and mental impacts of climate change (Myers et al., 2017).

Adaptation planning in Prairie Indigenous communities often considers Indigenous and local knowledge, along with climate change science and projections (Bruised Head, 2018; Okorosobo, 2018; Patrick, 2018a).

For example, the Blackfeet Climate Change Adaptation Plan (Blackfeet Nation, 2018) is informed by cultural observations of climate change impacts and Amskapi Piikani records kept through oral tradition and history. Stories of seasonal hunts, warrior activities, social obligations, gatherings of nations and many other important events have been maintained through oral retellings over hundreds of generations. Climate change is now emerging in these stories as they advance into the present and future. Science-based climate trends and projections were also used to develop the plan, which is built around sector-specific vulnerabilities and impacts. Goals, strategies and actions for climate change adaptation in eight sectors—including agriculture, water and forestry—are based on the Blackfeet understanding that people and nature are one, and that people can only be healthy if the health of the environment is also ensured. A dynamic view of the natural world and recognition of its reciprocal relationship with the Blackfeet is considered necessary to balance the needs of all *(see* Case Story 4.5).

Models are emerging for braiding together Indigenous knowledge and climate science in climate change adaptation planning. For example, Lynes and Boyd (2018) describe a planning process to develop a Local Early Action Plan, comprising strategies and actions to cope with and adapt to immediate priorities identified by Indigenous communities. The process includes a series of educational workshops and community dialogues, followed by an adaptation workshop. Climate change experts and local knowledge holders deliver joint workshops and dialogues with concepts translated into local oral and written language.

4.7.3 Adaptation mainstreaming

Mainstreaming is the systematic analysis of climate risk and inclusion of adaptation in decision-making and planning processes. Government staff in Manitoba and Saskatchewan assessed the adaptability of provincial policies to climate change and their ability to support sectoral adaptation. Participants identified opportunities to build the policy flexibility needed in an uncertain future climate (Bizikova, 2018). Assessments were most useful when climate change response was articulated as a policy goal, either during initial policy design or after policies had been in effect for some time, so that there was some evidence of their effectiveness.

Analysis and planning for water use and management in the Prairie provinces increasingly examine the implications of climate change (TransAlta Corporation, 2018; Patrick, 2018b). For example, a collaborative exploration of water management in the Oldman and South Saskatchewan river basins examined streamflow scenarios for the period of 2025 to 2054 (Sauchyn et al., 2016). Potential adaptation strategies, such as modifying existing infrastructure, building new infrastructure, changing operations to supplement environmental flows, reducing demand and sharing supply, were assessed in interactive modelling sessions. Findings indicate that forecast-based rationing, together with new expanded storage, could dramatically reduce water shortages. Similarly, Manitoba Hydro's climate change strategy (Manitoba Hydro, 2014) is informed by climate change projections and numerous studies across the Nelson-Churchill Watershed that highlight important spatial and temporal patterns in how climate change may affect its core business.

Governments and corporations are also starting to disclose climate risks to public and private assets *(see* Climate Disclosure, Litigation and Finance chapter). For example, Suncor (Suncor Energy Inc., 2018) reported that it is managing climate risks through facility design, operational procedures and insurance for damage

to, or loss of, assets, as well as production interruption. TransAlta Corporation (2018) similarly notes that it has experienced negative financial impacts from extreme climate events and is using insurance, retirement of older facilities, improved drainage infrastructure and the stockpiling of supplies to address risks. The company has used climate modelling and past costs to estimate possible future financial implications of the reduction or disruption of production capacity in a changing climate, as well as potential positive financial benefits (TransAlta Corporation, 2018). Risk controls include using dams for flood and drought control, capital maintenance, monitoring weather patterns and adjusting site operations.

4.7.4 Limitations of current adaptation and resilience planning

While most policies currently in place do not take future climate into account, adaptive management—an iterative approach to decision-making in the face of uncertainty—provides flexibility and potential for learning as climate conditions in the Prairies change. Adaptive management is designed to be more flexible and responsive to changing local conditions, and is centered on evidence-based decision-making that aims to reduce uncertainty through monitoring, experimentation and learning (Holling, 1978). For example, several energy and environmental policies governing the oil and gas sector in Alberta reflect adaptive management principles, which could allow operators to adjust as climatic conditions change (Cobb et al., 2015). However, a lack of attention to experimental design and vague or unenforceable reporting requirements can limit actual learning, and undermine the adaptive nature of this approach (Olszynski, 2017). Furthermore, widely varying opinions about climate change and its impacts on the oil and gas sector in western Canada (Wiensczyk, 2014) suggest that some firms, governments and sectors will rely on reactive adaptation measures, and may not be preparing for rapid climate change or environmental and socio-economic tipping points—which cause changes into new or different states (e.g. water for irrigation agriculture became unreliable after three dry decades, as described in Warren, 2016b).

A lack of determination or motivation to address climate change can also limit opportunities for institutional learning. An examination of the evolution of Manitoba's emergency and disaster management system found that, while extreme events generated opportunities for significant learning, policy changes were largely reactive initiatives driven by top-down decision-making, with reduced institutional evolution relative to other policy issues (Haque et al., 2018). Moreover, certain organizations may be reluctant to disclose climate risks due to concerns about company stock value or legal liability *(see* Climate Disclosure, Litigation, and Finance chapter). Some industry reporting may even conceal climate change impacts, lessening incentive for a better understanding or management of climate risks (Quest, 2015).

To enhance adaptation overall, adaptation planning requires regular evaluation of effectiveness, revision based on learnings, and enhanced progress reporting of what is being learned about climate change and adaptation in the Prairies. However, the limited reporting on progress delivered thus far has primarily focused on actions taken. For example, in Manitoba, provincial reporting on climate change and independent reporting from various government departments spoke to climate change risks and adaptation activity, but did not address the extent to which actions were successful at reducing or minimizing the most significant risks (Manitoba's Auditor General, 2017).

While adaptation-related performance metrics and the measurement of adaptation goal achievement are not yet common (Auditors General, 2018; Government of Saskatchewan, 2018), Saskatchewan has developed a framework for measuring progress achieved in making the province more resilient to climate change. Saskatchewan's Climate Change Strategy (Government of Saskatchewan, 2017) describes climate resilience and focuses on the principles of readiness, with a commitment to annual assessment and reporting. The strategy consists of 25 indicators of climate change in five key areas: natural systems, physical infrastructure, economic sustainability, community preparedness and human well-being (Government of Saskatchewan, 2018). This framework will enable the provincial government to track and report on progress in building resilience to climate change.

Another limitation of adaptation planning is the continued reliance on recent historic climate conditions to define future climate variability and extremes. Risk assessments often do not consider extremes outside the range of recorded observation (Sauchyn et al., 2014). Prolonged droughts, such as those that occurred during the period from the 1920s to the early 1940s, are a common feature of climate history in the Prairies, but predate such major industrial allocation of surface water as is used in oil and gas extraction. Taking such extremes into account in planning processes can help in identifying adaptation measures that may be robust enough to address low-probability, high-impact climate change scenarios that would have profound implications for water users (e.g., Sauchyn et al., 2015; EPCOR, 2017).

4.8 Moving forward

4.8.1 Knowledge gaps and research needs

The assessment of current knowledge presented in this chapter reveals gaps and needs for further research. Foremost among these are indicators and methodologies for assessing the effectiveness of strategies and actions that have been implemented. Other key knowledge gaps and needs include:

Best practices and guidance for:

- Incorporating model projections of future climate scenarios into adaptation planning. Many risk assessment processes are based on the analysis of recent historical climate scenarios. Without efforts to consider future climate projections in decision-making—as well as uncertainty in the projections of future climate—some firms, governments and sectors may not be sufficiently prepared; and
- Establishing, implementing, measuring and modifying the monitoring and evaluation of progress towards achieving climate resilience goals.

Improved understanding of:

- New opportunities arising from climate change;
- How agriculture could expand beyond the margins of the Prairie Ecozone and into treed zones of nutrient-poor forest soils;
- The social, environmental and economic impacts of sustained (multi-year) drought and of prolonged inundation of land under excessive wet conditions;
- The vulnerability and adaptive capacity of specific social groups, including low-income families and recent immigrants, and in particular differences between urban Indigenous populations and those in remote and rural communities; and
- How Indigenous knowledge can enhance adaptation and sustainable practices, and how to integrate Indigenous knowledge into adaptation planning processes.

4.8.2 Emerging issues

This assessment of the current knowledge of climate change impacts and adaptation in the Prairie provinces indicates the following emerging issues:

Transformational adaptation

As a warming climate amplifies regional weather extremes, the severity of floods, storms and droughts will exceed the historical experience of Prairie communities. Incremental adjustments made to historical practices and policies are unlikely to deliver adequate adaptation to the evolving hydroclimate and could potentially be maladaptive over time. Therefore, a significant emerging issue is the need for transformational adaptation that challenges existing policies, structures and systems.

Adaptation in rural communities

Recent rural social and economic trends, rural depopulation and increasing farm size, in particular, are factors that undermine the adaptive capacity of rural communities. Extension services in rural areas, previously provided by Prairie universities and government agencies, have diminished. Watershed stewardship groups and rural municipalities now provide these services to some extent, but lack the resources for adaptation planning.

Social and cultural considerations in adaptation decisions

Conventional approaches to evaluating the vulnerability of social groups based on indicators of exposure and adaptive capacity do not take into account cultural understandings of values and risk, local knowledge, certain causal factors of inequality and oppression, and unique capacities for agency, including contributions and insights derived from marginalized perspectives such as Indigenous knowledge and women's experiences.

Intersectionality perspectives

Positive emerging trends include an emphasis on climate policy and planning, and innovative approaches to accessing and interpreting knowledge to inform these processes, including integrating Indigenous understanding of climate change and adaptation (Myers et al., 2017; Lynes and Boyd, 2018). The emerging intersectionality perspective recognizes how multiple attributes and identities can intersect to affect vulnerability and adaptive capacity, while a focus on social infrastructure can draw attention to whether and how existing practices can be retained or revised for positive adaptation.

4.9 Conclusion

In the Prairie provinces, climate change is resulting in a redistribution of natural capital. It is transforming the seasons towards wetter winters and drier summers, and requiring changes to water resource management. The transition to a new distribution of water supplies and new regional ecosystems will be punctuated by phases of change as global warming interacts with regional variability and weather events. Collaboration among governments, municipalities and Indigenous communities is required to deal with the geographic shifts in the availability of water and ecological resources.

As climate change alters the frequency and intensity of extreme weather, the longer-term risks posed by climate change will include an amplified range of water levels and associated consequences: flooding, fire, water supply deficits, disturbance to ecosystems, and more variable forest and farm productivity. The increasing intensity of weather events represents an expanding deviation from a baseline climate, recognizing that the baseline, meanwhile, is also shifting. This ongoing state of change may ultimately be the most challenging scenario. Eventually temperature, precipitation and water levels will cross a threshold beyond which impacts will abruptly become more severe. Examples include the permanent loss of water stored as snow and ice, rainfall intensity that exceeds the watershed and storage capacity of infrastructure, and the loss of low temperatures that inhibit many pest and disease vectors from proliferating in agricultural and forested regions.

The response to climate change in the Prairie provinces has transitioned from recognizing to responding to potential impacts. Government agencies, private industry, Indigenous communities, municipalities and regional community organizations (e.g., watershed stewardship agencies, irrigation districts) are now engaged in resilience and adaptation planning. The net impacts of regional climate change will depend on the success, extent and scope of adaptation planning and its effective implementation. Plans have emerged in the past decade, and adaptation planning is on the agenda of many municipalities, corporations, industry associations and civic organizations. Each of the provincial governments in the Prairies has a climate strategy that incorporates adaptation, and most of the major cities are engaged in resilience planning, although implementation is in the early stages.

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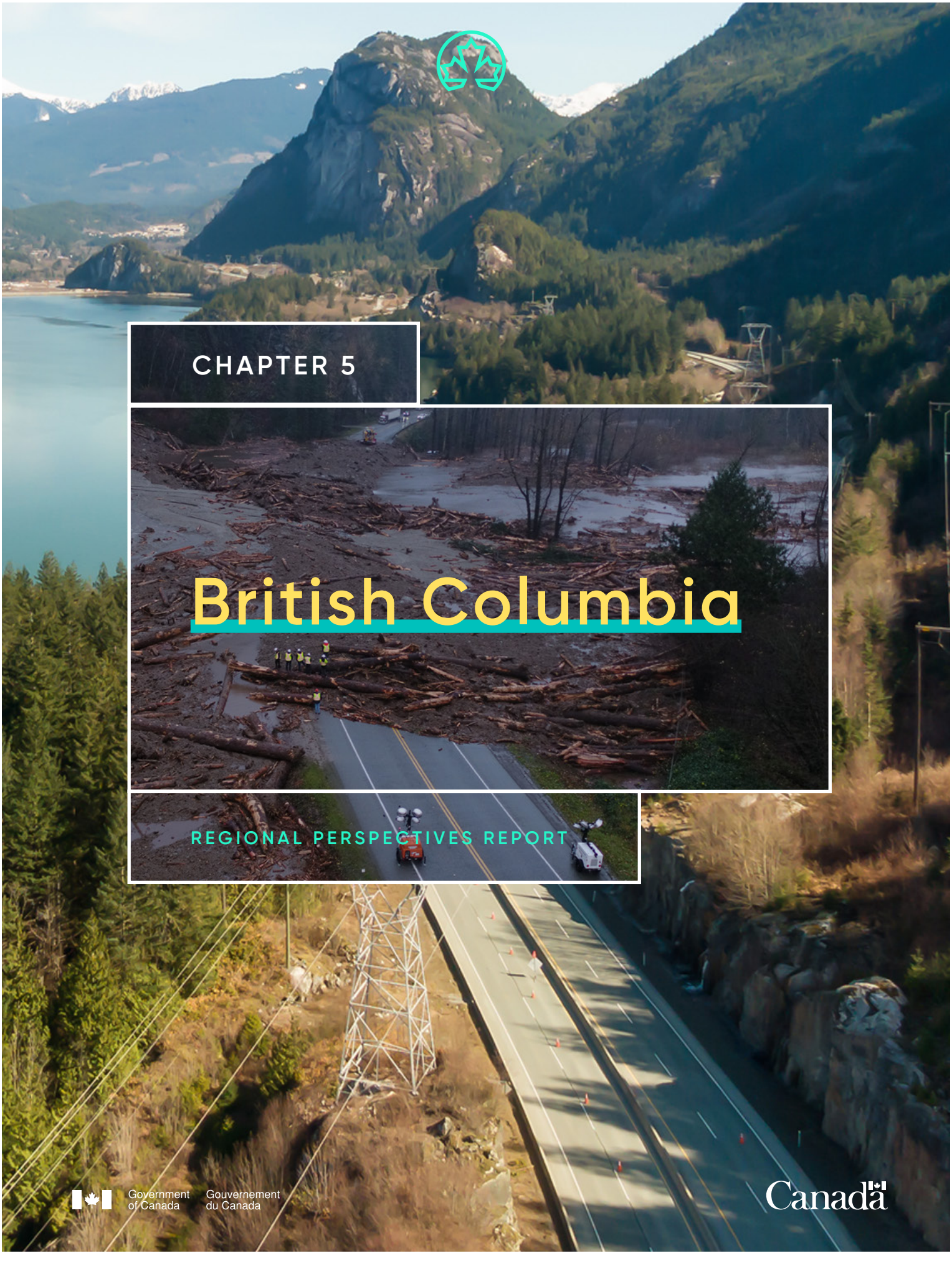

CHAPTER 5

British Columbia

REGIONAL PERSPECTIVES REPORT

Government of Canada / Gouvernement du Canada

Canada

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Key messages

Indigenous Peoples in B.C. are experiencing and adapting to climate change (*see* section 5.2)

Indigenous Peoples are uniquely impacted by climate change, and are also uniquely resilient as a result of Indigenous Knowledge Systems. Successful adaptation is more likely when co-created with Indigenous Peoples in ways that protect and strengthen Title, Rights, and jurisdiction, and when Indigenous Knowledge and unique connections to territories are respectfully acknowledged and thoroughly incorporated in all aspects of climate change related planning and action. Indigenous-led adaptation efforts are emerging across many traditional territories in what is today known as British Columbia, and often consider climate change adaptation alongside strengthening Indigenous governance and environmental stewardship.

Climate change brings increasing flood risks (*see* section 5.3)

British Columbia's water resources will see significant changes as the climate warms, with flooding causing some of the most damaging and costly impacts. Many communities in British Columbia are reducing the risks by proactively planning, designing and implementing flood adaptation projects, but increased action across all scales is needed.

Climate change is impacting British Columbia's forests (*see* section 5.4)

Climate change is profoundly affecting British Columbia's forests, as well as communities and infrastructure located in forested regions. The risk of disturbance from fire and pests is increasing due to climate change, affecting forest productivity, wildlife habitat, biodiversity and ecosystem services. Action to enhance forest resilience is still in the early stages, as policy, operational guidance and the necessary tools are being developed.

Building a climate-ready agriculture sector is critical (*see* section 5.5)

Climate change is already impacting food production in British Columbia. Continued collaborative efforts across B.C. are needed to help advance adaptation in the agriculture sector.

Adaptation continues to advance in B.C. (*see* section 5.6)

Climate change adaptation activities—including efforts focused on implementation—are present across most sectors and settings in B.C. This work continues to mature, supported by improved access to climate data, decision-support tools, funding, supportive institutions and collaboration. However, significant gaps remain and it is unclear whether current and proposed efforts will be sufficient given the extent of the risks faced and the costs of implementation.

5.1 Introduction

5.1.1 Provincial overview

British Columbia (B.C.) is characterized by its climatic and physiographic diversity (*see* Figure 5.1). The Pacific Ocean produces an immense amount of precipitation that is trapped in the western part of the province by the Coast and Cascade Mountains, rendering the B.C. west coast the wettest region in Canada. The ecosystems and landscapes of B.C. include temperate rainforests, semi-arid deserts, boreal forests and alpine tundras. Depending on the approach used to calculate gross domestic product (GDP), natural resource industries represent about 51.4% of B.C.'s GDP (Government of B.C., 2020c).

The population of B.C. was estimated at about 5.25 million as of October 2021 (B.C. Stats, 2021) and is growing by approximately 1% annually (Government of B.C., 2020f). Although most of the province's population is concentrated in urban areas in the Lower Mainland and on Vancouver Island, there are communities found across the province. Immigrants comprise almost 30% of the population—a proportion that has been steadily increasing since 2001—and about 18% of the province's population in 2016 consisted of senior citizens (age 65+), a proportion that is expected to grow to 26% by 2040 (B.C. Statistics, Ministry of Jobs, Trade and Technology, 2018).

Of the total number of Indigenous people in B.C. (270,585 in the 2016 census), about two thirds (63.8%) are First Nations people who reside both on and off reserve, with about one third (33.0%) being Métis and less than 1% being Inuit (Statistics Canada, 2017). The Indigenous population—both the on-reserve and the urban and away-from-home population—has been steadily growing over the past decade at a faster rate than the non-Indigenous population in B.C. (First Nations Health Authority, 2020a). The Province of B.C. recently introduced legislation to ensure that its laws are brought into line with the principles of the United Nations Declaration on the Rights of Indigenous Peoples (Government of B.C., 2020d), and over 50% of B.C.'s 200 Bands as identified in the *Indian Act* are participating in treaty negotiations processes, or have concluded treaties through such processes (B.C. Treaty Commission, 2020).

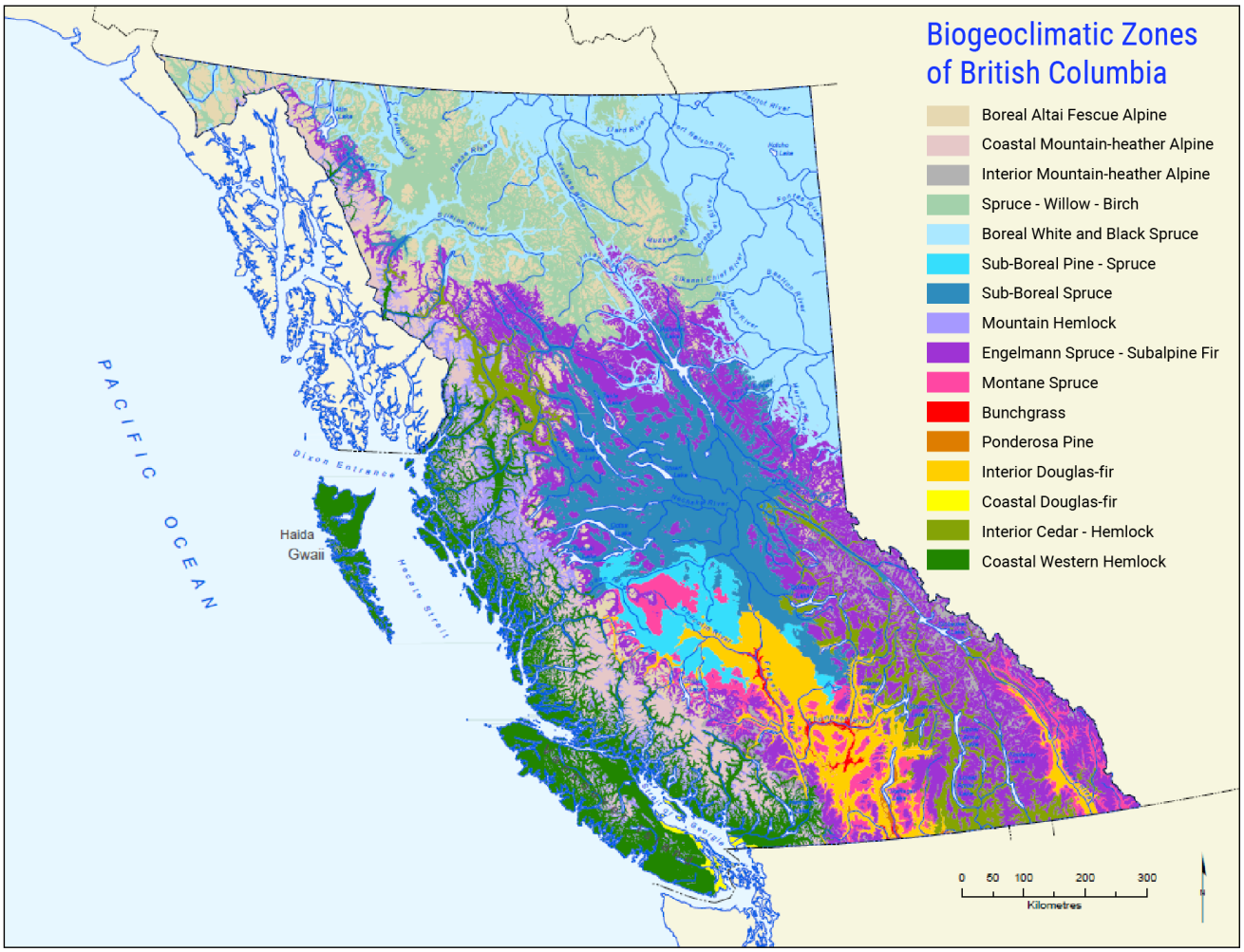

Figure 5.1: Biogeoclimatic zones of British Columbia. Source: B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018a.

Extreme weather events are having significant impacts on B.C.'s economy and on the health and well-being of its population. Recent extreme weather events in B.C. include the following:

- An atmospheric river event in November 2021 brought record precipitation to many areas of southern B.C., leading to destructive flooding in many communities (Schmunk, 2021), and extreme precipitation-triggered landslides, leading to mortalities and the failure of several highways in B.C. (Schmunk, 2021). Early estimates suggest that this atmospheric river event led to at least $450M in damage in the province (Charlebois, 2021).

- Between June 25 and July 1, 2021, peaking on June 27 and 28, much of B.C. experienced an unprecedented heat event. This event included record-breaking day-time and night-time temperatures, and led to 526 heat-related deaths between June 25 and July 1, 2021, with 96% of these deaths occurring in a residential setting (B.C. Coroners Service, 2021). A rapid attribution study determined that this event would not have occurred without climate change (Philip et al., 2021).
- In 2017, 2018, 2020 and 2021, smoke from fires in B.C., as well as fires from the United States, contributed to poor air quality in communities across the province. During the 2018 wildfire season, the air quality monitoring stations that recorded the most days during which air quality posed high health risks were the stations in Prince George (32 days), Castlegar (30 days), Quesnel (26 days), Williams Lake (20 days), Fort St. John (18 days), and in the Central Okanagan (18 days) and the South Okanagan (18 days) (Statistics Canada, 2019);
- A severe windstorm on December 20, 2018, battered B.C.'s south coast, and was the most damaging in B.C. Hydro's history (B.C. Hydro, 2019a). The event was unprecedented, with strong winds coming from multiple directions, sometimes exceeding 100 kilometres per hour, and with more than 400 millimetres of rain falling in some areas leading up to the storm, which destabilized trees. The storm left more than 750,000 customers without power—some for over a week—and thousands of damaged pieces of equipment (B.C. Hydro, 2019a); and
- A well-documented ocean warming event that started offshore of the west coast of B.C. in 2013 was evident in coastal waters by the summer of 2015, with an increase in water temperatures of 3 ˚C above normal (Ross, 2017). This warming of coastal waters was accompanied by harmful algal blooms, record-high levels of large gelatinous zooplankton, and invasion by warm-water species (*see* Sector Impacts and Adaptation chapter; Chandler et al., 2016).

Between 1948 and 2016, British Columbia experienced 1.9 °C of warming, as well as increases in daily minimum temperature, which is an important driver of change (Zhang et al., 2019). Warming has been more pronounced in northern parts of the province (*see* Figure 5.2). As described further below, these trends are projected to continue (*see* Figure 5.2).

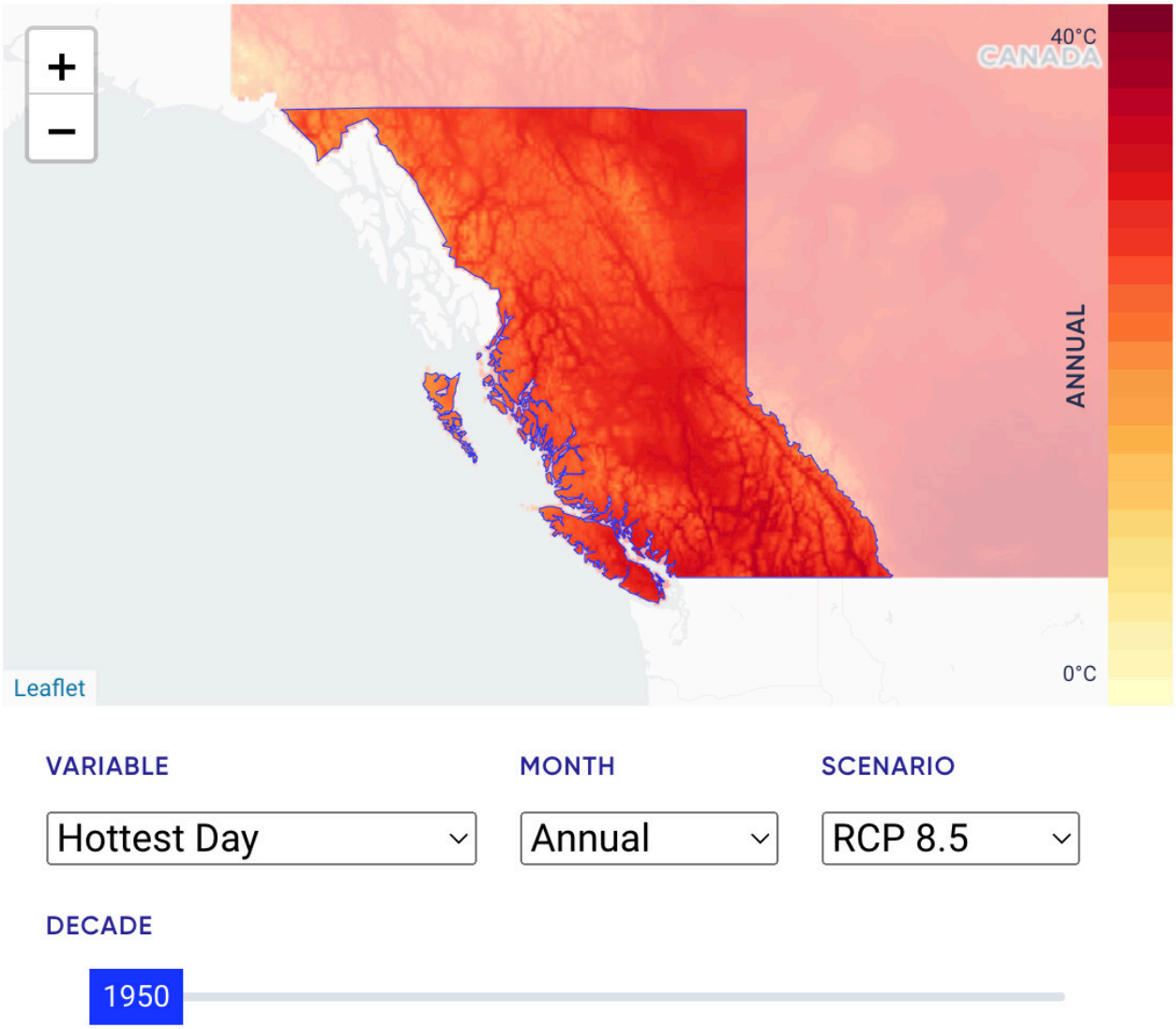

Figure 5.2: Interactive regional map of British Columbia that draws from climatedata.ca and visualizes various climate variables from 1980 to 2100 using a high emissions RCP8.5 scenario. On the interactive site, users can also explore the influence of different emissions scenarios on the projections.

Warming trends will drive a number of climate changes for B.C., including:

- **Warmer temperatures** in all seasons, leading to more extreme heat events and longer growing seasons (*see* Canada's Changing Climate Report). The annual average temperature in B.C. would increase by over 5°C by 2100, under the high emissions scenario, with warming most pronounced in the winter (Zhang et al., 2019). The number of days below 0°C will also decrease, leading to impacts on ecosystems, freeze-thaw cycles, the design of building heating systems, etc.;

- **Annual precipitation** increasing by 5.7% by 2050, and by 13.8% by 2100 under the high emissions scenario (RCP 8.5; Zhang et al., 2019). Changes in seasonal precipitation—including longer summer droughts—will pose a threat to current patterns of water accumulation (e.g., decreased snowpack, glacier mass loss) and discharge, and will lead to water scarcity issues in the summer, challenging B.C.'s ecosystems, agriculture and forestry industries, and communities (B.C. Ministry of Environment, 2016);
- **Extreme precipitation** events becoming more frequent and intense (Zhang et al., 2019), and increased frequency of atmospheric river events (Curry et al., 2019; Vadeboncoeur, 2016; Pinna Sustainability, 2014). These events will exacerbate the impacts associated with changes to seasonal precipitation: for example, by contributing to faster runoff, thus increasing the risk of flooding, landslides, and sediment and pollutant loading in drinking-water reservoirs and aquatic ecosystems;
- **Changes in streamflow**, including the timing of spring freshet, timing and duration of summer-autumn low flow, and higher water temperatures during low-flow periods (Bonsal et al., 2019), leading to increased flood risks and changes to aquatic ecosystems;
- **Changes to ocean conditions**, including stronger storm surges, rising sea levels and increasing acidification (Greenan et al., 2019; Vadeboncoeur, 2016), leading to increased flood risks and changes to marine ecosystems;
- **Increased wildfire risk** resulting from changing precipitation and temperature, along with changes to wind patterns (Bush and Lemmen, 2019) and shifts in ranges of pests such as the Mountain Pine Beetle (*Dendroctonus ponderosae*), leading to ecosystem changes and impacts on infrastructure and health; and
- **Changing forest conditions, and changes in plant and animal distributions** (Government of B.C., 2020e), leading to impacts on economic productivity, ecosystem health, and Indigenous health and wellness, etc.

5.1.2 Previous assessments and scope

The B.C. chapter in the previous national assessment (Walker and Sydneysmith, 2008) highlighted a general trend from research on climate change impacts towards adaptation action. The present chapter builds on these findings by assessing current knowledge to provide examples of observed and projected impacts from climate change in the province, examples of successful adaptation, as well as actions that can facilitate future adaptation. It focuses on five priority areas: Indigenous Peoples; water resources and flood management; forestry; agriculture; and adaptation planning and action. These areas were determined through an iterative process based on prior knowledge and targeted engagement with experts.

Focusing on key messages allows authors to address questions of greatest importance to adaptation decision making in B.C., rather than assessing all possible issues. The chapter has been supplemented by recently completed assessments—namely, by the B.C. chapters in the coastal assessment (Vadeboncoeur, 2016) and the transportation assessment (Nyland and Nodelman, 2017), the *Preliminary strategic climate risk assessment for British Columbia* (*see* Section 5.6; B.C. Ministry of Environment and Climate Change Strategy, 2019), *Canada's Changing Climate Report* (Bush and Lemmen, 2019), the *Health of Canadians in a Changing*

Climate: Advancing Our Knowledge for Action report (Berry and Schnitter, 2022), as well as by several chapters in the *Canada in a Changing Climate: National Issues Report* (Warren and Lulham, 2021) of this assessment (e.g., Sector Impacts and Adaptation, Water Resources, and Ecosystem Services).

5.2 Indigenous Peoples in B.C. are experiencing and adapting to climate change

Indigenous Peoples are uniquely impacted by climate change, and are also uniquely resilient as a result of Indigenous Knowledge Systems. Successful adaptation is more likely when co-created with Indigenous Peoples in ways that protect and strengthen Title, Rights, and jurisdiction, and when Indigenous Knowledge and unique connections to territories are respectfully acknowledged and thoroughly incorporated in all aspects of climate change related planning and action. Indigenous-led adaptation efforts are emerging across many traditional territories in what is today known as British Columbia, and often consider climate change adaptation alongside strengthening Indigenous governance and environmental stewardship.

First Nations are already experiencing impacts of climate change, including warmer temperatures, shifting precipitation, heat waves, wildfires and floods. These impacts also include loss of access to cultural sites and traditional foods and medicines, often exacerbated by the location of reserves, and by the legacy of colonization and systemic racism. Indigenous communities in B.C. are at various stages in addressing climate change; several communities have developed adaptation plans, and many of the initiatives are community-led. Critical to the development of these plans are the multigenerational, land-based Indigenous Knowledge Systems that date back thousands of years and continue to develop and evolve. Each community has a unique history, experience and distinct perspective on B.C.'s changing climate, yet Indigenous knowledge and experiences have been under-represented in climate change initiatives to date.

5.2.1 Introduction

Approximately one third of all First Nations communities in Canada—more than 203 communities—are located in B.C. (Government of Canada, 2010). There are seven language families comprising 34 distinct First Nations languages in B.C. and this high level of language diversity is unique in Canada (First Peoples' Cultural Council, 2018). First Nations territories in B.C. span diverse lands, water and marine ecosystems. This section focuses mainly on B.C. First Nations people living on reserve because of their defined geographical land connection and limited governing rights, as defined by the *Indian Act*, R.S.C. 1985, c. I-5.

Indigenous leaders have been actively bringing attention to the changing climate and finding ways to adapt to new conditions (Indigenous and Northern Affairs Canada, 2019; Wilson, 2019; Sanderson et al., 2015). This critical depth of understanding is often based on Indigenous Knowledge Systems, which are intrinsically interconnected with the territories from which they emerge and have been passed down from generation to generation since time

immemorial (Belfer et al., 2017). Globally, lands held or managed by Indigenous peoples and local communities are under increasing pressure from human activity including climate change, but are generally deteriorating less rapidly than other lands (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019a). Based on the findings of the Global Assessment Report on Biodiversity and Ecosystem Services (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019b), the United Nations is calling for Indigenous leadership and guidance to help address human-caused environmental destruction and climate change that threatens the survival of species worldwide.

First Nations communities in B.C. are closely connected to their territories, which are an important source of resilience; however, climate change exacerbates existing inequities resulting from colonization (Weatherdon et al., 2016; Downing and Cuerrier, 2011; Jacob et al., 2010; Turner and Clifton, 2009). Because of colonial violence and injustices, and ongoing systemic levels of discrimination, many Indigenous communities tend to be socioeconomically marginalized, and more susceptible to negative climate-related impacts. Despite the innate resilience of Indigenous Peoples, who have thrived through extreme variations in climate for millennia, their ability to address climate-related challenges has been profoundly affected by the historic inequitable relationship between Indigenous peoples in B.C. and the Government of Canada (Yumagulova, 2020). These challenges have been exacerbated by the provisions of the *Indian Act*. Despite the critical importance in informing climate change adaptation, Indigenous perspectives and values have been largely excluded from much of the contemporary climate discourse, resulting in further inequities and marginalization (Yumagulova, 2020).

The location of many reserves was arbitrarily established, breaking down pre-existing governance structures and rights, and disrupting cultural identities. Furthermore, the designated reserve lands included only a small portion of the First Nations' traditional territories and were often established in areas that were deemed economically uninteresting for the settler governments due to their vulnerability or unsuitability (e.g., their location in floodplains, downstream or downwind, and the downgrade of major industrial developments) (Yumagulova, 2020; Mascarenhas, 2007). The size and location of reserves also often make effective climate change adaptation planning challenging. Moreover, First Nations that are not self-governing are dependent on federal assistance with installing and maintaining their infrastructure, which is often inadequate, as seen in multi-year boil water advisories (Yumagulova, 2020).

5.2.2 Valuing Indigenous Knowledge Systems

Indigenous Knowledge and experiences have been under-represented in climate change assessments, policies and laws to date. The limited inclusion of Indigenous Knowledge Systems in climate change assessments to date has been acknowledged, but much more work is needed to develop processes for meaningful engagement with Indigenous Peoples and provide opportunities for them to define climate change related planning processes, to foreground their values and needs in the context of climate change adaptation, and to improve respectful inclusion of Indigenous Knowledge in these processes (Ford et al., 2016).

Under the umbrella of CleanBC, the province held 10 regional sessions in 2019 and 2020 to discuss issues related to climate change, and to work towards co-producing the provincial adaptation strategy (Government of B.C., 2020a; Indigenuity Consulting Group Inc., 2020). This effort was made after significant shortcomings were identified in the *Preliminary Strategic Climate Risk Assessment for British Columbia*, and indicates an

important step in building effective nation-to-nation relationships and true co-production. (B.C. Ministry of Environment and Climate Change Strategy, 2019).

The failure to recognize, include and respect Indigenous Knowledge Systems can result in adaptation efforts being less effective, especially for Indigenous Peoples (Nakashima et al., 2012). For instance, a study of 92 newspaper articles published from 1995 to 2015 focusing on Indigenous peoples in a climate change context across Canada, the USA, Australia and New Zealand (Belfer et al., 2017) revealed that Indigenous Knowledge Systems had identified almost twice as many climate change impacts as Western or scientific knowledge had done. The study also demonstrated that Indigenous Knowledge Systems tend to provide observations about sociocultural, health and safety impacts that otherwise often go unnoticed. This highlights the critical importance of working with Indigenous Peoples and seeking their leadership on these issues, as well as foregrounding the Indigenous Knowledge Systems that have developed over time and that have enabled place-specific sustainable living for millennia.

Acknowledging the value of the knowledge and rights of the Indigenous peoples, who have successfully stewarded their territories for thousands of years, holds the potential to create a solid foundation for innovative knowledge co-production and mutual learning for effective climate action. For example, a study of climate change and water at Stellat'en First Nation in B.C. combined knowledge from Western science and local Elders, and led to a series of recommended actions formulated by the First Nation (Sanderson et al., 2015). Implementation of these actions, including the creation of a community food garden and a ride-sharing hotline, has improved policy making and increased climate action in the community.

5.2.3 Climate change impacts for Indigenous communities in B.C.

Indigenous communities in B.C. are already experiencing substantial impacts associated with extreme weather events, many of which will increase in frequency and intensity as the climate continues to change (Government of B.C., 2020a; Indigenuity Consulting Group Inc., 2020). In addition, Indigenous peoples are noticing more gradual climate-related changes, such as the melting of glaciers, ocean acidification, rising sea levels, and changes in traditional food harvesting (Turner and Clifton, 2009). Climate change impacts present distinct challenges to Indigenous communities because of their unique worldviews that acknowledge the intrinsic interdependency with—and spiritual relationship to—their natural environment, and deeply rooted connection to their respective territories (Castleden et al., 2009; Lewis and Sheppard, 2005). This was reflected in the artwork done by youth Indigenous artists for a 2019 art contest (*see* Box 5.1). Traditional food sources, such as salmon, are not only an important nutritional source in many Indigenous communities in B.C., but they also play a significant part in cultural identity and social cohesion. Similarly, sharing traditional harvests with relatives, neighbours and those who are in need is one of the foundational elements of Indigenous community resilience.

Box 5.1: Fraser Basin Indigenous Youth Climate Art Contest

The Indigenous Youth Climate Art Contest was launched in 2019 by the Fraser Basin Council and invited Indigenous youth who live in B.C. to submit proposals to create visual stories about their perspectives on B.C.'s changing climate. Artwork from the winning artists is featured below (*see* Figure 5.3) in order to promote better understanding and representation of, and respect for, Indigenous youth perspectives in Canada's national assessment on climate change.

Youth from all over B.C. submitted proposals, and five of these proposals were chosen by the contest judges Tsēmā Igharas and Sheldon Pierre Louis. The winners of the art contest were:

- Leah Anthony, Nak'azdli Band, with the piece "UNEVEN GROUND: laying down complex root systems"
- Adrian Rain Flinn, James Bay Cree, Mistissini, with the collection "ᐅᑲᓇᐧᐁᔨᒨᐧᐁᐤ/ukanaweyimuweu"
- Sarah Jim, Tseycum First Nation, W_SÁNEĆ, with the piece "Saltwater Ways"
- Coralee Miller, Sylix, Okanagan Nation, with the piece "Red Woman," and
- Veronica Rose Waechter, Gitxsan Nation, with the piece "Legends of the Blue Sky."

More details about the contest, the winners and judges can be found here.

Figure 5.3: Samples of the artwork from the winners of the Fraser Basin Indigenous Youth Climate Art Contest

Seasonal cycles also play an important role in the lives of Indigenous peoples. For example, the presence of snow on mountains or the presence of specific plants can signal significant times for gathering, travelling, practicing specific ceremonies, and harvesting foods and medicines. Climate change is impacting all of these activities. Although Indigenous peoples often have limitations in accessing human, financial and political resources to address climate change, their commitment to uphold their roles as stewards and guardians of their territories is steadfast. The strong sense of responsibility and stewardship is demonstrated, for instance, through Indigenous Guardian Programs (Coastal First Nations, 2017; Indigenous Leadership Initiative, n.d.), Haida Marine Planning (Jones et al., 2010), and the Syilx Nations Stewardship Project to reduce wildfires (Forest Enhancement Society of British Columbia, 2019). As they have done for thousands of years, Indigenous people rely on their values of stewardship, laws and covenants with their territories.

Indigenous communities are at various stages in addressing climate change; some have produced and are implementing climate change adaptation plans, such as the following: the Ahousaht, Hesquiaht, and Tla-o-qui-aht Community-based Climate Change Adaptation Plan (Lerner, 2011); Gitgaa'at value-based climate change adaptation planning (Reid et al., 2014); Tsleil-Waututh's climate change planning (*see* Case Story 2.5 in Cities and Towns chapter); and the Toquaht Nation's Coastal Adaptation Plan (Toquaht Nation, 2018). Some communities are aware of climate change impacts, but are either unable or unsure of how to act due to long-term political, social and economic marginalization (Jacob et al., 2010). The support of the BC First Nations Leadership Council (FNLC) for the Assembly of First Nations Global Climate Emergency Declaration demonstrates that climate change is an increasingly important issue for First Nations in B.C. (First Nations Leadership Council, 2019). At the provincial level, the Chiefs-in-Assembly of the BC Assembly of First Nations and the Union of British Columbia Indian Chiefs have passed resolutions instructing these organizations to develop a First Nations Climate Change Strategy and Action Plan identifying actions that will lower greenhouse gas (GHG) emissions, reduce vulnerability to the impacts, and build capacity and resilience, as well as identifying low-carbon economic opportunities arising from adaptation (*see* Box 5.2). Funding programs are becoming more common, including the First Nations Adapt Program (Government of Canada, 2021) and the health-focused Indigenous Climate Health Action Program (First Nations Health Authority, 2021a).

Box 5.2: BC First Nations Climate Change Strategy and Action Plan

The First Nations Leadership Council (FNLC), made up of the BC Assembly of First Nations, the First Nations Summit and the Union of BC Indian Chiefs, as mandated by the Chiefs in BC, is developing a First Nations Climate Change Strategy and Action Plan (the Strategy) that will be informed by First Nation priorities and knowledge. The objective of the Strategy is to identify strategies and actions to reduce greenhouse gas emissions, to strengthen Indigenous climate leadership in B.C., to reduce vulnerability to impacts, and to build capacity, understanding and resilience in First Nation communities. The Strategy is intended to help guide climate responses while also communicating to governments and partners of priority areas. This will, in turn, remind governments and partners that successful climate action is possible only when co-created with First Nations in ways that protect and strengthen Title, Rights, and jurisdiction, and when Indigenous Knowledge and unique connections to territories are respectfully acknowledged and thoroughly incorporated in all aspects of climate planning and action.

The following subsections discuss Indigenous perspectives on climate change adaptation within the framework of four natural elements: water, land, fire and air.

5.2.3.1 Water

For many Indigenous communities, "water is life"—from the protection of glaciers and flowing waters into the ocean to the fluid in our mother's prenatal womb. Indigenous Knowledge connects individuals and communities to these waters and ignites their birth responsibilities to steward waters and land. With climate change, Indigenous peoples are experiencing changes in these water cycles, including receding glaciers, decreased snowfall, drought, and emergency situations such as flooding, leading to problems such as loss of access to clean drinking water, and interrupted or reduced access to traditional food sources and medicines, and impacts on mental health (*see* Video 5.1; Kitsumkalum Communications, 2018; Cave and McKay, 2016). Many of these impacts are exacerbated by systemic issues like federal inaction on boil water advisories resulting from inadequate infrastructure.

Many First Nations have reserve lands located in areas that experience recurring flood events, but lack adequate resources to address the issues (Partners for Action, 2019). Many First Nations, however, are attempting to collaborate with others to take action. For example, a Memorandum of Understanding between the Cowichan Tribes, Cowichan Valley Regional District, the City of Duncan and the Municipality of North Cowichan on Vancouver Island came into effect in 2010 to guide integrated flood management for the Lower Cowichan/Koksilah River (Government of B.C., 2020a; The Cowichan Tribes et al., 2010; Northwest Hydraulic Consultants, 2009). Dykes have been constructed on Cowichan Tribe lands to protect the community and divert flood waters, including from the Koksilah River. Like Cowichan Tribes, other Indigenous communities are also beginning to prepare for and adapt to extreme events, including through uptake of floodplain mapping technologies such as LiDAR.

Video 5.1: The connections between climate change and people's mental health in the Quw'utsun (Cowichan) River Valley. Source: https://www.youtube.com/watch?v=pCraV8ahpYo

In the Cowichan Region, severe recurring seasonal drought is threatening to reduce river flow to the extent that salmon runs will not be able to take place unless adaptive actions are taken (Cowichan Watershed Board, 2018). This is a significant change to the way that things used to be for First Nations: "The elders talk about salmon runs being so numerous that there were runs all year round and you could fish all year round" (Tim Kulchyski, Cowichan Tribes Fisheries Consultant). The knowledge of Elders is well-aligned with findings of the B.C. Wild Salmon Advisory Council, whose review found that salmon levels across all regions and species had declined since the 1950s (B.C. Wild Salmon Advisory Council, 2018). For example, in southern B.C., the sockeye population was reduced by 43% between 1954 and 2016 (B.C. Wild Salmon Advisory Council, 2018), making these salmon—an important cultural and spiritual animal as well as essential food source for Indigenous peoples in B.C.—particularly vulnerable to climate change. Salmon are also sensitive to several different climate impacts in different seasons, which further increases their sensitivity (e.g., increased winter precipitation can lead to earlier spring melt and higher temperatures during spawning) (Vadeboncoeur, 2016) (*see* Case Story 5.1).

B.C. First Nations are often excluded from government decision-making and management frameworks related to freshwater (Simms et al., 2016). However, evidence of collaborations and Indigenous-led initiatives suggests some progress. For example, the Cowichan Tribes co-chair the Cowichan Watershed Board together with the Cowichan Valley Regional District (CVRD). This process fosters a co-management opportunity between First Nations and local governments (Cowichan Watershed Board, 2018). While collaborative management of natural resources is challenging—especially when bringing together different worldviews in a culturally diverse partnership—the work of the Cowichan Watershed Board demonstrates the benefits of Indigenous co-governance.

A study that interviewed 50 community members and leaders from coastal First Nations in B.C. found that adaptation actions relating to governance and social capital emerged as strategies critical for climate change adaptation while infrastructure upgrades and natural resource management were not prioritized (Whitney et al., 2020). Results from this study were presented by the Coastal First Nations Great Bear Initiative and Fraser Basin Council (Coastal First Nations, 2020), and showed that the management of climate impacts cannot be separated from reconciliation and self-governance. The study also identified a number of salient climate impacts for coastal communities (Whitney et al., 2020). Studies such as this one are supplemented by initiatives at other scales. For example, Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) put in place the First Nation Adapt Program (FNAP), which provides funding to First Nation communities to address climate change impacts on community infrastructure and emergency management. The FNAP has funded many projects across B.C., including a project with Skidegate First Nation that is developing models to map sea-level rise and storm surge, and to identify impacts on coastal First Nation communities in B.C. (Government of Canada, 2020).

Case Story 5.1: What becomes of "Salmon People" without Salmon? The Stó:lō and Indigenous organizations' role in a changing climate

The Stó:lō—a word meaning "river" or "the Fraser River" in Halq'eméylem—have inhabited the Lower Fraser River watershed since time immemorial. Stó:lō people comprise a supra-tribal collective of Halq'eméylem-speaking peoples whose traditional territory extends from Yale to Langley, B.C. For the Stó:lō, this place is *S'ólh Téméxw* ("Our World" or "Our Land"). Their connection to the territory is expressed in their self-identification as "People of the River" (Schaepe, 2007; Carlson, 2001).

The Stó:lō Research and Resource Management Centre (SRRMC), based in Chilliwack, B.C, is a branch of Stó:lō Nation: the political amalgamation of eleven Stó:lō communities. The SRRMC provides land and water stewardship support, and investigative stewardship support, for the collective Stó:lō community. Its mandate is to protect, preserve and manage Stó:lō heritage according to the principles of Stó:lō stewardship.

The Stó:lō were historically deprived of their right to self-govern and to determine the use of their traditional lands and resources, which have been fundamentally altered since pre-contact time (Duffield, 2001; Woods, 2001; Thom and Cameron, 1997). Notwithstanding current procedures for consultation and accommodation, development and resource extraction continue to exert pressure upon the Stó:lō people's traditional lands, resources and waterways (Brady, 2014). This pressure is compounded by climatic changes, which ultimately impact resources that are essential for Stó:lō subsistence, cultural practices, spiritual connections to ancestors, and cultural survival.

Semi-structured interviews with SRRMC staff and Stó:lō community members indicate that climatic and climate-induced impacts, along with other drivers of cumulative effects, are contributing to shifts in the availability, seasonal patterns and geographical distribution of traditional resources. These shifts exacerbate the Stó:lō people's already restricted access to traditional resources, which include traditional plants and medicines (e.g., Western red cedar, berries), wildlife and, most notably, Fraser River salmon (McHalsie, 2007). The Fraser River salmon are an integral aspect of Stó:lō history, ecology and identity. The salmon are regarded as ancestors and compose the primary staple in Stó:lō traditional diet (McHalsie, 2007; Smith, 2001; Deur, 1999; Cameron, 1997). The shifts described above are affecting the Stó:lō fisheries and food security, the timing and conduct of Stó:lō ceremonies, access to Stó:lō traditional foods, and the ability of the Stó:lō to exercise cultural practices and teachings. Overall, these changes exert multiple impacts on Stó:lō health and emotional well-being. Climate-induced changes are projected to increasingly affect Stó:lō traditional territory through declines in snowfall, changes to the Fraser River's hydrology and temperature, and reductions in Fraser River salmon availability (Shrestha et al., 2012; Healey, 2011; Ferrari et al. 2007; Morrison et al. 2002). Figure 5.4 summarizes the results regarding climate-induced and cumulative effects to Fraser River salmon.

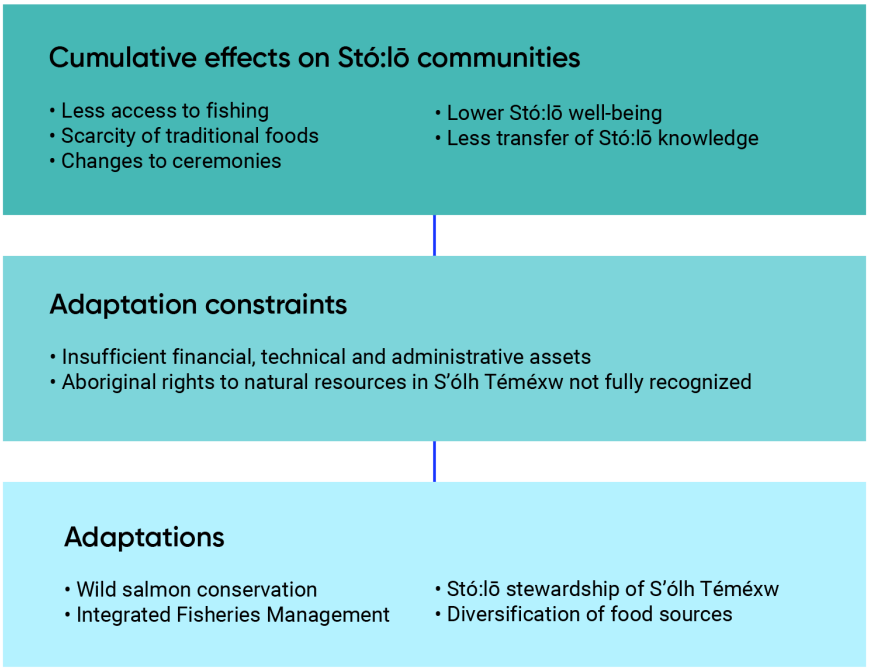

Figure 5.4: Summary of Fraser River salmon-related results.

Stó:lō community members have reported barriers in adapting to such effects, with special reference to financial and capacity constraints. Another major constraint lies in the lack of recognition of Stó:lō Aboriginal rights to manage traditional territories. In addition, consultation processes in B.C. often overburden First Nations' technical and administrative capacities, and fail to lead to meaningful reconciliation (Booth and Skelton, 2011; Marsden, 2006; Baker and McLelland, 2003). Nonetheless, the Stó:lō are actively coping with changes and exerting adaptive capacity. Stó:lō community members are identifying environmental changes and adapting accordingly to maintain continuity in their cultural practices and identity. For example, Stó:lō communities and organizations are involved in wild salmon conservation advocacy and integrated fisheries management, practicing Stó:lō stewardship of wild salmon and of *S'ólh Téméxw*—the Stó:lō traditional territory—as a whole.

The Stó:lō Research and Resource Management Centre supports Stó:lo adaptive capacity by filling technical and research capacity gaps, preserving Stó:lo culture and knowledge, and supporting Aboriginal rights and title. The SRRMC is also involved in adaptation planning with Stó:lō communities. Academic engagement with the SRRMC highlights the primary role that Indigenous organizations can play in facing the challenge of adaptation, as this organization is unique in that it combines technical capacity and expertise with cultural values and community knowledge.

In conclusion, advancing reconciliation in a changing climate entails the recognition and support of existing Indigenous adaptive capacity, including the capacity embedded in Indigenous organizations. Furthermore, the recognition of Indigenous rights, such as through meaningful consultation processes, is paramount for communities to be able to exercise stewardship of threatened traditional resources.

5.2.3.2 Land

The unique relationships that Indigenous people have with their territories and lands have developed through careful stewardship over thousands of years and are reflected in the profound sense of relational connection (LaDuke, 1999). Indigenous-managed lands in Canada have been found to have slightly greater levels of vertebrate biodiversity than do protected areas, while also supporting a greater number of threatened vertebrate species; partnerships between Indigenous communities and other government agencies could enhance biodiversity conservation efforts (Schuster et al., 2019). The impacts of climate change are manifested in various ways and affect Indigenous communities both environmentally and socially (Turner and Clifton, 2009). One example is that less severe winters have contributed to devastating outbreaks of the Mountain Pine Beetle, reducing overall forest health (Parkins, 2008). Indigenous livelihoods have been impacted because many communities have economic interests in both timber and non-timber products retrieved from forests. Changes in traditional food availability, ranging from caribou to saskatoon berries, as well as access to medicinal and ceremonial plants such as salal or cedar, have significant social, health and cultural implications for First Nations (Marushka et al., 2019).

Landscapes are changing rapidly, and the cumulative impacts of industrial resource extraction and climate change make cultural and livelihood retention challenging in Indigenous communities (Turner and Clifton, 2009). Mainstream land management practices rarely align with Indigenous Knowledge Systems, and communities seldom have authority in how they would like the lands to be governed (Simms et al., 2016).

Despite enormous challenges, there are some promising examples of effective Indigenous climate change adaptation projects on the land, such as caribou conservation. Caribou herds of critical importance to Indigenous peoples in northern B.C. are at extremely high levels of risk (Booth and Skelton, 2011). The cumulative impacts of forestry, roads, mining, and oil and gas industries have destroyed almost two thirds of the caribou habitat in B.C. (Johnson et al., 2015). Climate change poses another significant threat to caribou and their habitat (Masood et al., 2017). According to Roland Willson, Chief of the West Moberly First Nations in northeast B.C., the decline in the caribou population has transformed his traditional way of life (Huffington Post, 2015). Studies conducted by the First Nation document community losses due to the inability to harvest caribou. This crisis led to a partnership between the West Moberly First Nation and Saulteau First Nation to develop caribou management plans for the surviving caribou herds, resulting in restoration efforts that have effectively regenerated one herd from 16 to 70 animals in the span of four years (Newton, 2018). Key actions included implementing maternity pens, applying a self-determined ban on hunting caribou, using a traditional predator management program, and systematically monitoring and mapping the caribou habitat. The First Nations also negotiated a draft Caribou Recovery Partnership Agreement with both the Government of British Columbia and the Government of Canada (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019a), which outlines areas of protection, restoration and conservation, including predator management measures and an Indigenous Guardianship program.

5.2.3.3 Fire

Many communities in B.C. are experiencing increases in the length of the forest fire season and the severity of wildfires. These wildfires continue to devastate Indigenous communities, resulting in displacement from

homes and homelands, serious physical and mental health impacts, economic impacts and threats to community infrastructure (Abbott and Chapman, 2018), as well as impacts to cultural heritage and cultural rights. Indigenous communities face inequities in situations of wildfire crisis in terms of preparedness, response and recovery (Abbott and Chapman, 2018). The First Nations Leadership Council (FNLC) issued a news release outlining the issue of jurisdiction between federal and provincial governments in managing the wildfire crisis that is affecting First Nations communities, underscoring the urgent need for emergency planning and implementation assistance, training, funding and collaboration with all levels of government (First Nations Leadership Council, 2018). Addressing the gaps in emergency response is an important priority for First Nations in B.C.

People living on First Nations reserves in Canada are 33 times more likely to experience evacuations due to wildfire than those living off reserve (Yumagulova, 2018). An online engagement survey, launched in 2018 as part of the B.C. Flood and Wildfire Review following the 2017 and 2018 wildfire events that affected many Indigenous communities, yielded the following results: two-thirds of the respondents focused solely on the wildfires; half thought that their community was unprepared for wildfire events; over three-quarters supported prescribed burning; and one third considered that they had received unclear information regarding evacuation (Abbott and Chapman, 2018).

Many First Nations communities are proactively addressing and preparing for wildfire. ʔaq̓am, a Ktunaxa Nation community, needed to evacuate 110 people from 37 homes due to a 2017 wildfire. The fire damage was extensive, but could have been much worse had relationships not been built with the Regional District of East Kootenay and the City of Cranbrook prior to the wildfire. ʔaq̓am hosted a community celebration to express gratitude to its neighbours for their support. As Chief Joe Pierre reminds us, “Relationships need to be worked on all the time. Neighbours that know each other, help each other” (Abbott and Chapman, 2018). Indigenous communities such as the ʔaq̓am Community are utilizing Indigenous Knowledge Systems along with Western science to address, prepare for and manage forest fire risk, including through prescribed burning. These efforts are supported by programs like the Union of BC Municipalities’ (UBCM) Community to Community (C2C) Forum, which was designed specifically to help First Nations and local governments connect (Union of BC Municipalities, 2021).

Many Indigenous communities in B.C. used burning practices to enhance landscapes and manage the land. Prior to colonization, these traditional fire uses were practiced on a large scale to promote the growth of important foods, such as berries, and to support animal migration (Turner, 1999). Current fire suppression policies have meant that these practices are not being used to the same degree anymore. Oral tradition has documented these practices, and some Indigenous elders have recollection of these practices. Fire practices are still in use today, though on a smaller scale and with the primary purpose of hazard management and reducing wildfire risks to nearby communities (Lewis, et al. 2018). Indigenous Knowledge Systems include knowledge of how to burn safely, and about the interconnections between fuels, fire behaviour and weather. An example of a community-led effort to manage wildfire is the Revitalizing Cultural Burning project coordinated by the First Nations Emergency Services Society (FNESS), in collaboration with three First Nations in B.C.: the Shackan Indian Band; Xwisten (Bridge River) First Nation; and Yunesit’in Government (First Nations Emergency Services Society, 2022). According to FNESS, the project broadens learning opportunities about cultural burning revitalization to strategic partners such as the provincial and federal governments, and through stories/case studies on (i) advancing cultural burning revitalization in relation to

reconciliation, wildfire prevention and risk reduction, and climate change adaptation; and (ii) enhancing holistic knowledge and observations of wildfire management to inform climate change adaptation planning for First Nations communities of similar scale and needs (British Columbia Assembly of First Nations, 2020, 4–5).

Fire management practices are also part of stewardship, and fire suppression is related to the ability to be good stewards (Forney, 2016).

5.2.3.4 Air

The elements of water, earth and fire are visually easier to conceptualize than air. The space that we occupy as humans is generally through the atmosphere that supports our ability to breathe and to exist, which is based on good air quality. Our symbiotic interdependence with oxygen-producing plants is one example of what Indigenous Knowledge Systems refer to as interconnection and as an interdependent relationship with the natural world (Caverley, 2011).

Climate change affects the air in multiple ways, including through higher temperatures—leading to drought and evaporation—and through poor air quality stemming from wildfire smoke, resulting in a range of social, health and cultural impacts on Indigenous Peoples. Knowledge holders in the Clayoquot Sound area have noted an increase in storm severity and a decrease in storm frequency (Lerner, 2011). Through a collaborative climate adaptation planning process, the Ahousaht Nation, Hesquiaht Nation and Tla-o-qui-aht Nation identified approaches for responding to more severe storms. One of the adaptation responses identified in this plan is to upgrade key community assets to better perform during storm surges, flooding and rain, wind and windthrow (Lerner, 2011). The Ahousaht, Hesquiaht and Tla-o-qui-aht Community-based Climate Change Adaptation Plan outlines many adaptation strategies that interconnect to support the overall community vision. An example of these resilience-enhancing strategies is the effort to promote cultural self-reliance and continual learning about climate change.

5.2.3.5 Indigenous Food Systems

Indigenous Knowledge Systems related to harvesting plant foods involve taking into account many complex variables, including elevation, season and preferred growing climates (e.g., dryness, shade, proximity of trees). Climate change has, and will continue to have, greater impacts on food sovereignty for Indigenous peoples than for non-Indigenous people. Climate change impacts (e.g., increased air temperature) will affect the growing season of plant foods and medicines. Shifting climate patterns negatively impact traditional food harvesting and result in food that is harder to locate, less abundant, and changed in consistency or taste. Indigenous peoples rely on traditional foods for their health, culture, identity, stewardship and political roles. Work is needed, including through Indigenous-led study, to find the best ways to adapt traditional foods in response to climate change. For instance, there is a relative lack of research on the effect that climate change will have on berry harvesting.

Indigenous Knowledge Systems include sustainable harvesting practices, such as the “first harvest practices.” For instance, huckleberries are an important food for the Ktunaxa people; Ktunaxa elders shared a practice whereby women carry the responsibility for picking the first huckleberries of the season for their family,

followed by praying for a good harvest that year (Forney, 2016; Williams and Clarricoates, 2002). These berries are used in important ceremonies throughout the year, including at important times in one's life. Berry pickers play a role in the health of huckleberry patches. Values such as respect for and reciprocity with the plants themselves are part of the good stewardship that Indigenous people practice. Other impacts to food systems arise as a result of changing ocean conditions. These issues too are being address by Indigenous-led efforts. For example, the First Nation Health Authority's Health Canada-funded project *We All Take Care of the Harvest (WATCH)* focuses on Indigenous seafood safety, security and sovereignty in the context of climate change (First Nations Health Authority, 2021a).

5.2.4 Conclusions

Indigenous Knowledge and experiences are often under-represented in climate change discourse and initiatives. Failing to appropriately make space for Indigenous Knowledge Systems in climate change adaptation initiatives has consequences for Indigenous peoples, including the repeat of maladaptive adaptation policies. Acknowledgement of the relative lack of engagement of Indigenous Knowledge Systems is needed to understand how meaningful inclusion can be achieved (Ford, et al. 2016).

Making space for these Indigenous Knowledge Systems promotes relationship building based on respect and understanding for Indigenous values, histories and worldviews. Treating Indigenous People and their Knowledge Systems on an equal footing with Western systems will empower Indigenous Peoples to develop their own climate adaptation programs. It will also help to promote collaboration at all levels of government, leading to true, long-term partnerships that enable climate change adaptation planning developed by Indigenous Peoples and Nations for Indigenous Peoples. Emerging evidence indicates that collaborative efforts to bring together Indigenous Knowledge Systems and scientific approaches, based on culturally appropriate and responsive strategies, would be actively supported and would help to ensure ongoing engagement in climate change adaptation plans (Wildcat, 2013).

The lack of autonomy to govern and make decisions regarding Indigenous lands and territories is a barrier for many successful adaptation efforts. Historic and current colonization efforts have systematically separated Indigenous peoples from their lands, as well as dismantled Indigenous Knowledge Systems in myriad ways, including through residential schools (Greenwood and Lindsay, 2019). Climate change has in some ways intensified the effects of colonization: "A central theme is that anthropogenic climate change is intimately connected to the ideologies, systems and practices of colonialism, and that the impacts on Indigenous peoples can be conceptualized as an intensification of the process of colonization (Jones, 2019, 73)." Indigenous rights and self-determination are an important aspect of the health and survival of Indigenous peoples. Indigenous-led climate change adaptation initiatives that address inequities, support reclamation of self-determination and are grounded in Indigenous ways of knowing can help to repair and restore the health of the land and to ensure collective survival and well-being (Greenwood and Lindsay, 2019).

5.3 Climate change brings increasing flood risks

British Columbia's water resources will see significant changes as the climate warms, with flooding causing some of the most damaging and costly impacts. Many communities in British Columbia are reducing the risks by proactively planning, designing and implementing flood adaptation projects, but increased action across all scales is needed.

British Columbia faces significant risks from coastal, riverine, and urban flooding. These flood events negatively impact critical infrastructure and services, ecosystems, and health and well-being. While there are many useful resources (e.g., floodplain mapping), and examples of planning and action at different scales, challenges remain, including complex and often overlapping jurisdictional mandates, long-term uncertainty and trade-offs, and limited human and financial resources. Opportunities exist to mainstream flood risk management into existing municipal practices (e.g., integrated storm water master plans, asset management), and research continues to build a strong economic case for action.

5.3.1 Introduction

Climate change is altering and will continue to alter hydrological regimes in B.C., negatively impacting riverine ecosystems and marine ecology (B.C. Ministry of Environment, 2016; Vadeboncoeur, 2016). In addition to high-flow events, changes in streamflow will very likely impact the timing and duration of summer-autumn low flow, and lead to higher water temperatures during low-flow periods (Bonsal et al., 2019). These periods of low flow represent decreased water availability, and can impact aquatic ecosystems and drinking-water supply (Bonsal et al., 2019). For example, the Cowichan Valley Regional District's 16 watersheds are impacted by increasing water use and a changing climate, requiring adaptation to deal with lower water levels in the Cowichan River (Watershed Governance Dispatch, 2019) (*see* Cities and Towns chapter for a discussion of adaptation options pursued). Changes to hydrological regimes also have the potential to affect hydroelectricity, B.C.'s primary source of electricity (Canada Energy Regulator, 2020).

5.3.2 Flood hazards

5.3.2.1 Riverine flooding

Riverine flooding is widespread in B.C. (*see* Figure 5.5) and occurs when forces such as excessive rains or rapid snowmelt exceed the capacity of a river channel or stream bank (Abbott and Chapman, 2018). An atmospheric river event in November 2021 brought record precipitation to many communities in southern B.C., leading to destructive flooding in many communities (*see* Box 5.3; Schmunk, 2021).

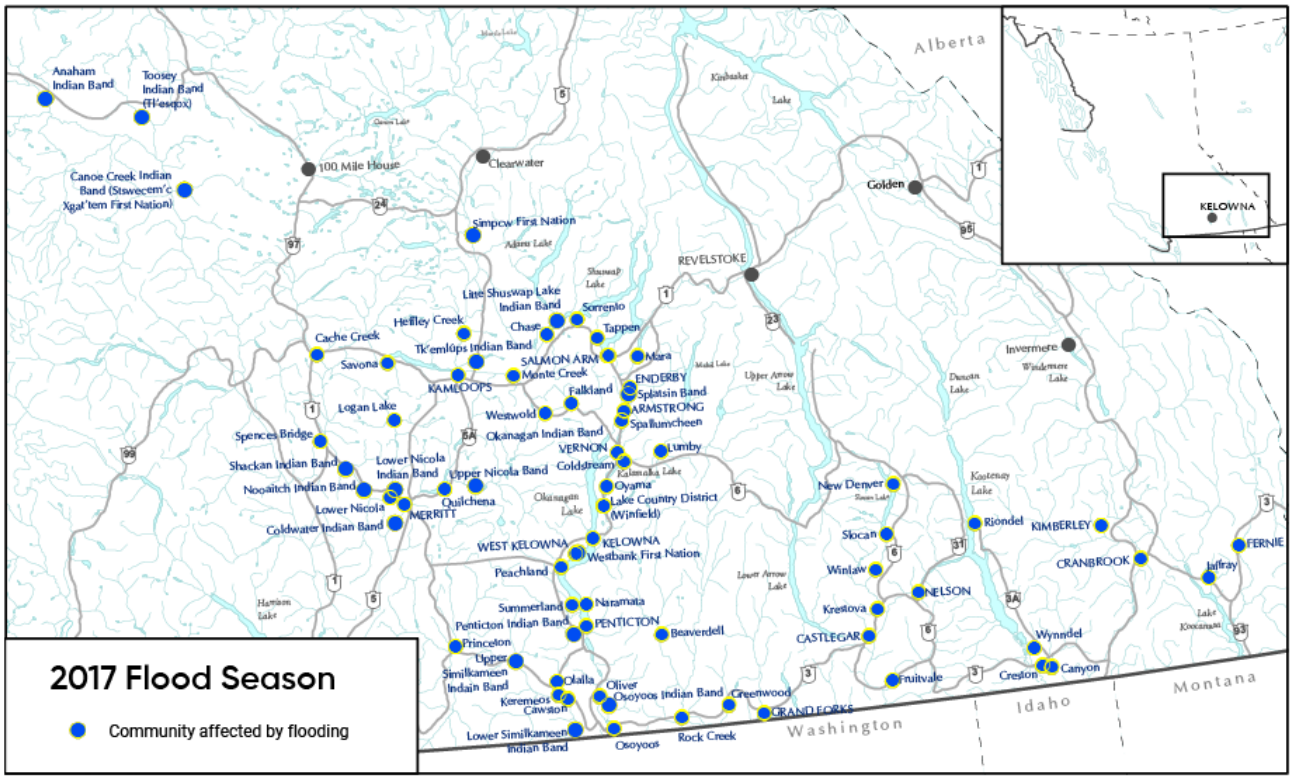

Figure 5.5: Map showing communities located in inland British Columbia that were affected by flooding during the 2017 flood season. Source: Abbott and Chapman, 2018.

Increasing temperatures and changes in seasonal precipitation will alter current patterns of water accumulation (e.g., decreased snowpack, glacier mass loss) and discharge, including the timing of spring thaw, timing and duration of summer-autumn low flow, higher water temperatures during low-flow periods (Bonsal et al., 2019), and increased strength and frequency of atmospheric river events (*see* Box 5.3) (Curry et al., 2019). These changes will be influenced by natural climate variability associated with El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) (Vadeboncoeur, 2016).

Box 5.3: Atmospheric Rivers

Atmospheric rivers are narrow bands of concentrated moisture in the atmosphere that enter western Canada from the Pacific Ocean and can lead to extreme precipitation events such as those witnessed in November 2021 (Bonsal et al., 2019). Such atmospheric rivers can be up to 1,600 km long and more than 640 km wide and, on average, carry an amount of water equivalent to 25 Mississippi Rivers (CBC Radio, 2021).

Climate change is likely to increase the strength and frequency of these events in British Columbia's Fraser River Basin (Curry et al., 2019).

Although there is uncertainty regarding how higher temperatures and reductions in snow cover will combine to affect the frequency and magnitude of future snowmelt-related flooding (Bonsal et al., 2019), available research indicates that riverine flood risk will increase in many parts of the province (B.C. Ministry of Environment and Climate Change Strategy, 2019; Engineers and Geoscientists British Columbia, 2018). Flood hazards in the Fraser River Basin, for example, would increase substantially under RCP 8.5 as a result of the increased strength and frequency of atmospheric river events (Curry et al., 2019).

As part of the Lower Mainland Flood Management Strategy, the Fraser Basin Council led the creation of a set of maps that show the extent of flooding in the Lower Mainland under various climate scenarios. These maps indicate a substantial increased risk of large flood events for much of the region (Auditor General of British Columbia, 2018).

5.3.2.2 Coastal flooding

B.C.'s coastline extends for more than 26,000 km and is a zone of considerable vulnerability to flooding resulting from rising sea levels and storm surges, especially in low-lying areas (Vadeboncoeur, 2016). B.C.'s coast will face increased flood risk as sea levels rise and high-water events become more common. Relative sea-level rise under a high-emissions scenario is projected to exceed 50 cm by 2100 for Prince Rupert, Haida Gwaii, and the Vancouver area (Cohen et al., 2019; *see* also Figure 7.16 in Greenan et al., 2019 for more locations). There is also the potential for much greater sea-level rise due to the melting of Antarctic ice (Greenan et al., 2019). For Vancouver, this would result in sea-level rise of approximately 135 cm by 2100 (Greenan et al., 2019). The frequency and magnitude of extreme high water-level events will also increase where the sea level is rising (Greenan et al., 2019). These events are typically associated with storm surges that coincide with high tide levels (Greenan et al., 2019).

5.3.2.3 Urban flooding

Urban flooding occurs when extreme precipitation events overwhelm municipal storm water infrastructure, leading to localized flooding that can create widespread impacts to property values, service provision, and health and safety (*see* Cities and Towns chapter for more information). Although local governments often understand the historical occurrences of urban flooding events in their communities, no research exists that characterizes this risk across the province. Similarly, local planning exercises often assess the future likelihood and consequences of urban flooding events (e.g., City of Prince George, 2021), but to date these results have been difficult to summarize at the provincial scale. Given the projected increases in extreme precipitation, and the challenges of ageing infrastructure and intensive development, it is likely that urban flood risk will increase alongside riverine and coastal risks (Auditor General of British Columbia, 2018).

5.3.3 Observed and projected impacts

Flooding affects infrastructure, natural systems and assets, health and well-being, and requires significant local, provincial and federal resources (B.C. Ministry of Environment and Climate Change Strategy, 2019). For

example, it is estimated that the widespread flooding in November 2021 caused $515M in insured damages in B.C. (Insurance Bureau of Canada, 2022). Wildfires often lead to hydrophobic soils, and it is likely that the significant 2021 wildfire season exacerbated the volume and speed of runoff during the November 2021 atmospheric river event (Clague, 2021).

Extreme precipitation events can trigger landslides, as was seen in November 2021 when landslides led to mortalities and the failure of several highways in B.C. (Schmunk, 2021). For a discussion of the impacts of flooding on air and marine transport infrastructure (e.g., Vancouver International Airport, Port of Metro Vancouver), see Vadeboncoeur et al. (2016) and Nyland and Nodelman (2017).

Flooding also negatively impacts human health as well as the health system itself (*see* also Health of Canadians in a Changing Climate; Burton et al., 2016; Du et al., 2010). For example, extreme precipitation events can lead to an increase in the cloudiness of water with mud and silt, as well as enteric diseases (e.g., cryptosporidiosis, giardiasis) in drinking water systems (Chhetri et al., 2019).

Coastal communities face impacts to their coastal infrastructure, ecosystem damage and coastline erosion (Greenan et al., 2019; Vadeboncoeur, 2016). The risks associated with these events are expected to increase as the sea level rises and as storm surge events become more frequent and intense. Flooding also creates unique challenges for Indigenous communities, some of which are discussed above (*see* Section 5.2). Agricultural land and freshwater sources may also be affected by salinization, through a build-up of salt in the soil (B.C. Agriculture and Food Climate Action Initiative, 2013).

As part of Phase 1 of its Lower Mainland Flood Management Strategy, the Fraser Basin Council projected the damage and direct and indirect economic losses in Lower Mainland floodplain areas that would result under different flood scenarios (*see* Table 5.1; Fraser Basin Council, 2016). This represents the most detailed study of the future economic impacts of flooding available in B.C.

Table 5.1: Economic loss projections for coastal and riverine systems in the Lower Mainland flood area (Fraser Basin Council, 2016)

FLOOD SCENARIO	RESIDENTIAL[1]	COMMERCIAL[1]	INDUSTRIAL[1]	PUBLIC/ INSTITUTIONAL BUILDINGS[1]	INTERRUPTED CARGO SHIPMENTS[2]	INFRASTRUCTURE[3]	AGRICULTURE[4]	TOTAL
A | Coastal (Present Day)	$5.6 B	$6.3 B	$1.6 B	$720 M	$3.6 B	$1.4 B	$100 M	$19.3 Billion
B | Coastal (Year 2100)	$7.1 B	$8.6 B	$2.6 B	$910 M	$3.6 B	$1.8 B	$200 M	$24.7 Billion

FLOOD SCENARIO	RESIDENTIAL[1]	COMMERCIAL[1]	INDUSTRIAL[1]	PUBLIC/ INSTITUTIONAL BUILDINGS[1]	INTERRUPTED CARGO SHIPMENTS[2]	INFRASTRUCTURE[3]	AGRICULTURE[4]	TOTAL
C | River (Present Day)	$2.6 B	$3.8 B	$1.6 B	$880 M	$7.7 B	$4.6 B	$1.6 B	$22.9 Billion
D | River (Year 2100)	$6.6 B	$7.6 B	$2.9 B	$1.2 M	$7.7 B	$5.0 B	$1.6 B	$32.7 Billion

Table 5.1 summarizes economic loss projections for all types of loss included in this vulnerability assessment, across the entire region, based on longer-duration flood: a two-week coastal flood (Scenarios A and B) or four-week Fraser River Flood (Scenarios C and D).

Notes

[1] Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation and wages.

[2] These are revenues from delays and cancellations in cargo shipping.

[3] Included in infrastructure are electrical substations.

[4] These losses include agricultural buildings and equipment damaged or destroyed, lost farm gate sales and replanting costs.

5.3.4 Flood risk reduction strategies

Flood risk management in B.C. occurs across the four pillars of disaster management, namely i) planning and preparedness, ii) prevention and mitigation, iii) response, and iv) recovery (Abbott and Chapman, 2018), and involves a multitude of actors, including federal, provincial and local governments, First Nations, non-government organizations, utilities, educational institutions and the private sector (Government of B.C., 2021a). Municipalities are often primary drivers of flood risk management (Auditor General of British Columbia, 2018). For example, land-use decisions—which are essential for risk prevention and reduction—generally fall within the jurisdiction of municipalities, regional districts and/or First Nations, as does the creation of storm water master plans, which were an early example of adaptation in the province. Efforts to manage flood risks are supported by researchers across the country (e.g., design guidelines being prepared by the Canadian Standards Association and the National Research Council of Canada, and the Pacific Institute for Climate Solutions' large-scale research projects aimed at creating a strategic approach to coastal

adaptation in B.C.) (Pacific Institute for Climate Solutions, 2021). See Table 4.2 in the Water Resources chapter for a list of national and provincial resources relating to flood risk management.

5.3.4.1 Riverine

B.C.'s Lower Mainland contains 600 km of dyking and 100 pump stations (Government of B.C., 2018b). This infrastructure has been designed to reduce flooding associated with the Fraser River and coastal areas, but it is not sufficient in all cases (Northwest Hydraulic Consultants, 2016a). The Lower Mainland Flood Management Strategy (Fraser Basin Council, 2016) resulted in the creation of several maps that are designed to support planning and preparedness in the Lower Mainland (Fraser Basin Council, 2019).

The B.C. River Forecast Centre monitors riverine flood risk in the province and issues advisories, watches and warnings as appropriate (B.C. River Forecast Centre, 2021). These early warning mechanisms are supplemented by emergency response mechanisms like GeoBC and Emergency Management BC's Emergency Management Common Operating Picture (COP) Portal. These provincial resources provide emergency GIS information and are the primary mechanism for displaying real-time emergency response data for emergency management personnel across B.C., and they have been used during both wildfire and flood events (Emergency Management B.C., 2019).

In 2018, the Auditor General of B.C. concluded that the provincial government may not be able to effectively manage the increasing flood risk posed by climate change (Auditor General of British Columbia, 2018). There is no existing research that assesses the adaptation gap across all levels of government for flooding in B.C.

5.3.4.2 Coastal

Many municipal and regional governments are engaged in planning activities that seek to manage coastal flood risk (Chang et al., 2020). Protection, accommodation and retreat are the general adaptation approaches used to reduce the risks of sea-level rise (*see* Figure 5.6). There is an increased understanding of these approaches, as can be seen in the compendium produced during the development of the North Shore Sea Level Rise Adaptive Management Strategy (Kerr Wood Leidal, 2020). Managed retreat via voluntary buyout is an important strategy that is often politically and emotionally charged (Rutledge, 2017; Gibbs, 2016), and that must consider efficiency, social acceptability and political feasibility in order to be effective (Thistlethwaite et al., 2020). The most prominent example in B.C. comes from Grand Forks, which was awarded funding from Infrastructure Canada's Disaster Mitigation and Adaptation Fund, in part to purchase properties located in floodplains (Government of Canada, 2019).

Land-use planning can prevent development in areas that are vulnerable to sea-level rise. An example of this is the City of Surrey's policy to regulate development within the Serpentine and Nicomekl River Floodplains, which restricts subdivision within the floodplain in order to limit the number of exposed businesses and residences. Combined with the City's Hazard Area Development Permit requirement (City of Surrey, 2022), the policy ensures that those living in or reconstructing a building in the floodplain will have buildings constructed to safe elevations. An understanding of flood risks and subsequent land-use planning are the foundations of this strategy (*see* Case Story 5.2).

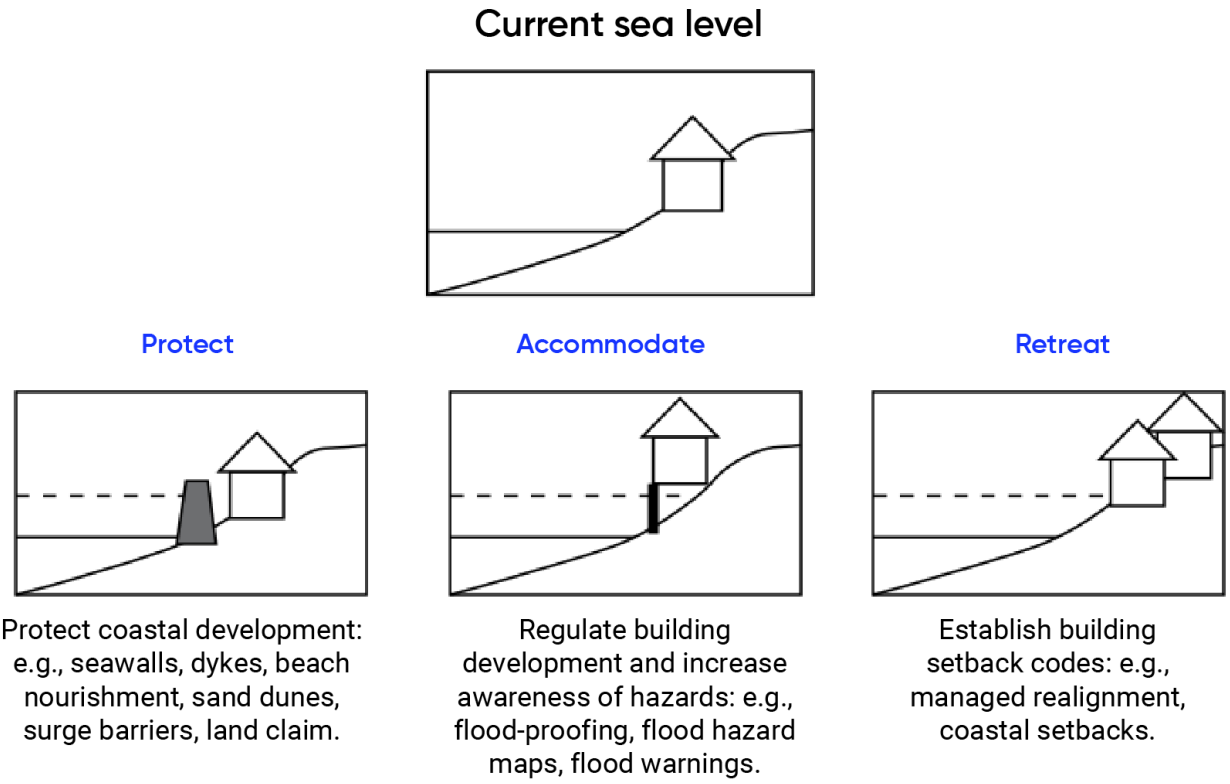

Figure 5.6: Schematic representation of protection, accommodation and retreat responses to sea-level rise. Source: Mercer Clarke et al, 2016, as modified from Linham and Nicholls, 2010, based on IPCC, 1990.

In 2019, the Government of British Columbia updated its Flood Hazard Land Use Management Guidelines to specify that all lots created through subdivision must have viable building sites on natural ground that are above the year 2100 flood construction level (considering 1.0 m of sea-level rise). An example of this can be seen in North Vancouver's Harbourside development, which was required to raise the entire site by 1.5 metres and to stabilize the foreshore (Richter, 2020).

Although engineered defences (e.g., dykes, tidal gates and pump stations) are often essential to protect people, property and infrastructure (Doberstein et al., 2019), planners are also considering the use of nature-based solutions that can be adapted to local conditions, in part due to their potential cost-effectiveness and for the co-benefits that they deliver (*see* also Ecosystem Services Chapter; Reguero et al., 2018). Many of the most populated coastal communities in the Salish Sea region have had asssessments conducted regarding their local potential for green infrastructure—as well as the vulnerability of the green infrastructure itself. Findings indicate that coastal green infrastructure can provide high coastal protection benefits (Conger and Chang, 2019). These approaches are sometimes augmented by solutions that rely on Indigenous Knowledge. For example, researchers are currently exploring the many co-benefits of clam gardens for coastal adaptation (e.g., through wave attenuation) (Lokman and Tomkins, 2020).

Coastal adaptation decisions often require collaboration between different levels of government and First Nations. Waterfronts, for example, are within the jurisdiction of the Government of British Columbia to administer Crown land approvals, and within the jurisdiction of the Government of Canada for the evaluation of impacts on fisheries and navigable waters (West Coast Environmental Law, 2018). The City of Vancouver's sea-level rise plan is informed by traditional Musqueam canoe landing protocols and requirements, a process that required a great deal of investment in trust building and collaboration.

The capacity of local governments to respond to changing coastal conditions varies greatly, as does the level of funding and support for coastal adaptation and vulnerability reduction. Larger municipalities like Vancouver, Surrey and Victoria have been able to source or leverage funding, while smaller communities often rely on support from higher levels of government when available (Chang et al., 2020). Furthermore, municipal governments do not have jurisdiction over the placement of certain types of critical infrastructure, such as railways, ports, airports, hydro infrastructure, pipelines, ferry terminals and highways. This infrastructure is often located in floodplains, placing it at risk to flooding, which requires collaborative adaptation efforts (Nyland and Nodelman, 2017).

5.3.4.3 Urban

Municipal governments have been managing storm water for many decades, and generally have a sense of their vulnerabilities and priorities, usually through storm water master plans. Much of this work is supported by guidance and funding from others level of government and has resulted in integrated storm water master plans, and various infrastructure upgrades (City of Surrey, 2022).

Low-impact development practices (LIDs) can significantly improve storm water management (*see* Cities and Towns chapter). Where LID features are applied in a neighbourhood, storm flows are reduced, water quality is improved, and base flows to creeks are sustained or improved over conventional storm water treatments (Dagenais et al., 2014). Some typical LIDs being used in B.C. communities include rain gardens, green roofs, infiltration galleries, bioswales, soil augmentation, downspout disconnections, lot grading, and on-lot cisterns/ retention systems. The Municipal Natural Assets Initiative increasingly supports municipalities in developing resilient, long-term infrastructure alternatives at substantial savings compared with engineered adaptation options (*see* Case Story 2.2 in the Cities and Towns chapter; *see* also Ecosystem Services chapter).

5.3.5 Key challenges and opportunities

In 2018, the Auditor General of B.C. found that local governments require more financial support, more reliable data and knowledge, stronger policies and plans from the federal and provincial levels, and additional human resources to improve flood risk management (Auditor General of British Columbia, 2018). A case study in Vancouver and Surrey identified the following five barriers to effective adaptation: inadequate collaboration, absence of senior-level political leadership, lack of public awareness, insufficient financial and staff capacity, and misalignment of policies within and between levels of government (Oulahen et al., 2018).

Some additional challenges faced by communities as they manage increasing flood risk include:

- **Governance:** A now-prominent report released before the flooding in November 2021 proposed a new model for flood risk governance in B.C. (Ebbwater Consulting, 2021), and the November 2021 floods have created a significant level of activity across all levels of government. However, at the time of writing, the outcomes of these activities are not known.
- **Data availability**: Many adaptation measures, particularly those involving engineering solutions, require high-quality data and rigorous options analysis. A survey of 72 B.C. communities indicated that only 31% had access to floodplain maps created using LiDAR (B.C. Real Estate Association, 2015). The Columbia Basin Trust recently accessed $2 million in funding to perform LiDAR mapping of the region.
- **Controversial trade-offs**: Community efforts to adapt to sea-level rise may focus on one particular community interest, such as the protection of private homes or an important economic resource, such as a port. When exploring options to reduce flood risk, it is important to balance objectives based on a broader understanding of community values (Educating Coastal Communities About Sea Level Rise, 2019; Capital Region District, 2015).
- **Significant financial consequences**: The costs of both action and inaction will be high, and communities generally cannot afford to reduce all aspects of climate risk, nor can they afford to build to the worst-case scenario. The estimated cost of installing a hard seawall can be in the order of $33,000 per lineal metre, whereas a more natural approach to shoreline protection is estimated at $10,000–$14,000 per lineal metre (Lamont et al., 2014). —Although less costly, this amount is still high for a small community's budget. For example, the Town of Qualicum Beach on Vancouver Island has approximately three km of coastline in its central waterfront, which would cost at least $30 million to protect using natural approaches. Implementing such measures therefore usually requires contributions from higher levels of government or external funding (including from organizations such as the Federation of Canadian Municipalities) to assist with planning, design and construction.
- **Short- and long-term implementation**: Adaptation is a continuous process. Assets are designed with lifespans of many decades, and it is important to recognize that the climate will continue to change throughout that timeframe, thereby posing risks to asset performance. An emerging practice is the incorporation of climate risk into formal asset management planning, a process for which guidance exists (*see* Water Resources Chapter; Asset Management B.C., 2018). In other situations, it may be possible to design for a less distant climate future, where uncertainty is minimized and the asset can be modified as part of planned maintenance or upgrading, if needed.

Case Story 5.2: Surrey's Coastal Flood Adaptation Strategy

As a coastal community, the City of Surrey, B.C., is expected to experience more flooding in the future as a result of climate change (e.g., sea-level rise and changes in precipitation patterns) and due to the region's low-lying topography (*see* Figure 5.7). Approximately 20% of Surrey's land lies within a coastal floodplain. Several sectors are at risk from flooding, including agriculture, recreation and transportation (*see* Case Story 7.8 in the Sector Impacts and Adaptation Chapter), as well as infrastructure, communities, and local and regional economies. The city was in need of a comprehensive adaptation strategy that considered climate change impacts to different sectors and stakeholders, examined different adaptation options and solutions, and identified long-term strategic directions, as well as shorter-term actions that could be used by multiple stakeholders to collectively manage and adapt to climate change impacts. To proactively address these needs, the city has developed a Coastal Flood Adaptation Strategy (CFAS) (City of Surrey, 2019).

Figure 5.7: Coastal area of Surrey, B.C. Photo courtesy of the City of Surrey.

The CFAS project team included experts from multiple disciplines; the process was guided by a multi-departmental steering committee, and partnerships with external organizations played a key role throughout the project's five phases. The collaborative work was grounded in rigorous technical analyses—including modelling of current and future flood extent, depth and velocity—and infrastructure vulnerability assessments.

Aside from designing complex engineered coastal flood resilience solutions, coastal adaptation planning often involves making difficult decisions about valuable assets, public funds and the future of existing communities. To balance these trade-offs, the CFAS challenged the long-held practice of keeping flood management decisions solely within the domain of professional engineers, and instead sought to bring community and stakeholder voices into the decision-making process. To achieve meaningful public engagement, the process incorporated structured decision making and impact-scenario planning (City of Surrey, 2019). This approach helped to integrate shared community values into the development of an inclusive plan that was publicly and politically supported. Over the three-year planning process, more than 30 organizations, agencies and governments, including First Nations, participated in the project. Over 2,000 residents and other stakeholders attended workshops, open houses, focus groups, project surveys and other engagement events. Communications related to the CFAS generated over 250,000 social media impressions, major national media coverage and almost 4,000 views of project videos.

Strategic directions on adaptation were developed through an iterative adaptive design process. Initially, over 20 adaptation concepts were co-developed with the community, professional stakeholders and academic partners. These concepts were assessed for feasibility, evaluated using community-identified values as criteria, and presented to stakeholders for further feedback and prioritization (*see* Figure 5.8; City of Surrey, 2018a). The selected long-term strategic directions subsequently guided the identification of 46 actions to be implemented over the next 80 years.

Implementation of the CFAS actions will involve numerous departments within the City of Surrey, outside agencies, senior levels of government and community-based organizations. The Strategy is an example of how a proactive, community-focused planning approach was successful in developing the partnerships and buy-in necessary to advance 13 major infrastructure projects valued at $187 million, which includes $76.6 million of Government of Canada funding through the Disaster Mitigation and Adaptation Fund. These projects address priority needs within the community and include the use of innovative approaches, such as nature-based solutions.

	Baseline – no adaptation	Current conventions	Mud Bay barrier	Highway 99 realignment	Managed retreat
Values criteria					
Residents *People permanently displaced*	Far worse	Slightly worse	No change	Slightly worse	Far worse
Agriculture *Permanent loss of agriculture land*	Far worse	Slightly worse	No change	Slightly worse	Far worse
Environment *Impacts to wetland habitats, freshwater fish habitat and riparian areas*	Moderately worse	Far worse	Far worse	Slightly better	Far better
Infrastructure *Percent of service/transportation infrastructure made vulnerable*	Far worse	No change	No change	No change	Slightly worse
Economy *Revenue*	Far worse	Slightly worse	No change	Slightly worse	Moderately worse
Recreation *Diversity of recreational opportunities*	Far worse	No change	Slightly worse	Slightly better	Moderately better
Culture *Opportunities for traditional practices*	Slightly worse	No change	Moderately worse	No change	No change
Impact and risk of failure					
Overall risk	Very high	Very high	Very high	Medium	Very low
Cost criteria					
Capital cost	–	$100m – $1b	More than $4b	$1b – $4b	$1b – $4b
Operation and maintenance cost	More than $10m	More than $10m	$1m – $10m	$1m – $10m	Less than $1m
Other infrastructure cost	More than $100m	$10m – $100m	Less than $10m	$10m – $100m	More than $100m
Future adaptation cost	$1b – $4b	$1b – $4b	$1b – $4b	$1b – $4b	Less than $100m

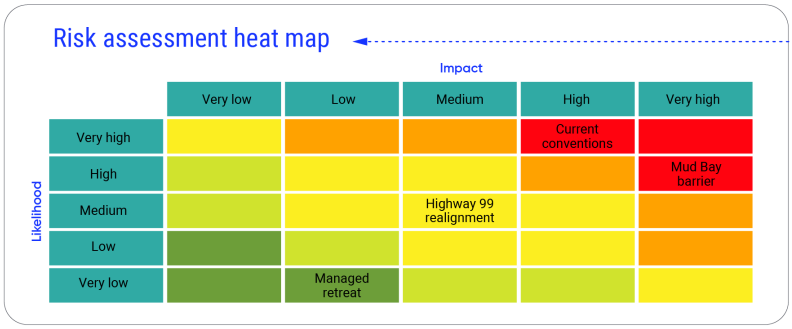

Figure 5.8: The City of Surrey's Coastal Flood Adaptation Strategy was developed using graphics that distilled complex technical information and facilitated meaningful public and stakeholder engagement. Featured here is an example of an evaluation matrix for the shortlisted adaptation options for Mud Bay, one of the three CFAS study areas. Source: City of Surrey, 2018b.

5.3.6 Conclusions

A changing climate means increased flood risk for much of British Columbia. In addition to high flow events, changes to the timing and duration of summer-autumn low flow and higher water temperatures will likely impact ecosystems negatively. B.C. experiences hazards from riverine, coastal and urban flooding, and some strategies, adaptation responses and governance processes are in place to reduce these risks. However, a

number of key challenges are present that represent urgent areas of action given the level of risk faced. The flood events in November 2021 highlighted the importance of improving flood risk governance in B.C.

5.4 Climate change is impacting British Columbia's forests

Climate change is profoundly affecting British Columbia's forests, as well as communities and infrastructure located in forested regions. The risk of disturbance from fire and pests is increasing due to climate change, affecting forest productivity, wildlife habitat, biodiversity and ecosystem services. Action to enhance forest resilience is still in the early stages, as policy, operational guidance and the necessary tools are being developed.

Forests are important economic, recreational and cultural resources for the people of British Columbia, as well as home to a wide range of species. Key climate change impacts in forested regions include increased incidence of wildfire, pest outbreaks, water stress and the introduction of new diseases. Changes in forest disturbances and productivity lead to changes in wildlife habitat, biodiversity, and ecosystem services, such as water supply, provision of timber and carbon storage. Adapting forest management practices is critical and involves understanding the climate change information needs of different users, as well as their capabilities to apply this information in decision making, and in the development and implementation of tools, such as FireSmart.

5.4.1 Introduction

B.C.'s forest resources provide the basis for the forestry industry, which makes a significant contribution to the provincial and local economies. In 2018, the total value of B.C. forest sector manufacturing shipments was just under $18.4 billion, with nearly $14.9 billion in exports (forestry is the leading export sector in B.C.) (Forestry Innovation Investment, 2019). Over 52,000 people are employed in the sector, which, in 2018, contributed 2.9% to the province's GDP and just under $1 billion to provincial revenues (Forestry Innovation Investment, 2019).

The diversity of ecosystems and species reflects the diversity of climates in B.C., which can vary substantially over relatively narrow ranges in elevation and horizontal distances (Moore et al., 2010; Meidinger and Pojar, 1991). These ecosystems provide a wide range of services to society. A changing climate could result in species at any given location being maladapted to their new climate (Wang et al., 2012; Aitken et al., 2008; O'Neill et al., 2008). At the stand and landscape levels, climate change could result in increased risk of disturbance by drought stress, fire, insects, disease and loss of productivity (*see* Sector Impacts and Adaptation Chapter; Dymond et al., 2016; Haughian et al., 2012; Sturrock et al., 2011; Woods et al., 2010), and changes to hydrological regimes and aquatic resources (Pike et al., 2010).

Climate change will have substantial social, cultural and economic consequences for the province (Abbott and Chapman, 2018). Adapting forest management practices will minimize the negative impacts of climate change and take advantage of potential benefits (Auditor General of British Columbia, 2018; Spittlehouse, 2005). However, challenges exist in translating knowledge into action (Shannon et al., 2019).

5.4.2 Biophysical impacts

Forestry needs to deal with both near-term impacts—largely related to changes in disturbance regimes—and longer-term changes in forest composition, structure and productivity. The net effect will be changes in ecosystem goods and services, such as the provision of timber, water, biodiversity, carbon sequestration, and in the cultural and social values associated with forests. The direction of those changes will depend on many factors, including whether the range of an ecosystem is expanding or contracting, other climate-induced changes that alter forest processes (e.g., regeneration, pest and pathogen susceptibility), and non-climate factors (e.g., management approaches). Not only will there be less predictability, but changes are expected to occur in ecosystem boundaries, forest structure and the incidence of disturbances (Fettig et al., 2013; Haughian et al., 2012).

Increased temperatures and reduced summer precipitation have already increased the length of the forest fire season and the occurrence of high fire-risk conditions in parts of B.C. (Kirchemeier-Young et al., 2019) affecting human health, property values and timber supply (Abbott and Chapman, 2018,). For example, the 2017 and 2018 fire seasons each set records, the first for the most buildings destroyed and people evacuated, and the second for the largest area burnt in a year—exceeding the record from the previous year (Government of British Columbia, 2019a, b). Tens of thousands of people were evacuated and the resulting health issues (e.g., respiratory problems, stress), property damage and expenditures related to fire fighting were widespread (Abbott and Chapman, 2018). The fires also resulted in reductions in estimates of midterm timber supply in the B.C. Cariboo Region (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018b). In 2021, a tremendously challenging wildfire season led to a provincial state of emergency being declared on July 21, 2021, and remaining in effect for 56 days until September 14, 2021 (Government of B.C., 2021b).

Increased disturbances from fire, insects, disease and water stress correspond to an increase in salvage logging to recover some timber value. Over a number of years, such disturbances may also result in a reduction in forest productivity and in timber available for harvest (Metsaranta et al., 2011). Existing management practices can have unintended consequences: the protection of timber supply through fire suppression in combination with changing climatic conditions may have set the stage for the Mountain Pine Beetle outbreak in the 2000s that killed approximately 60% of the mature pine forest in the B.C. Interior (Carroll, 2017). This, in turn, resulted in a short-term increase in harvest levels to promote salvage, but projected decreases in longer-term harvest levels (*see* Figure 5.9). Road building associated with the surge in harvesting has changed habitat conditions for wildlife and other species (Bunnell et al., 2011), and this may compound the influence of climate-induced changes on wildlife habitat and migration corridors (Stralberg et al., 2019). A changing climate is also expected to impact operations. For example, a shorter winter season increases costs by reducing the period of time available for road construction and hauling, and when logging can take place on more sensitive soils (Kuloglu et al., 2019). Other insects and diseases that are endemic to

B.C.'s forests may become more prominent in the future (Fettig et al., 2013; Sturrock et al., 2011; Woods et al., 2010), with potentially similar negative consequences for timber productivity and harvest levels.

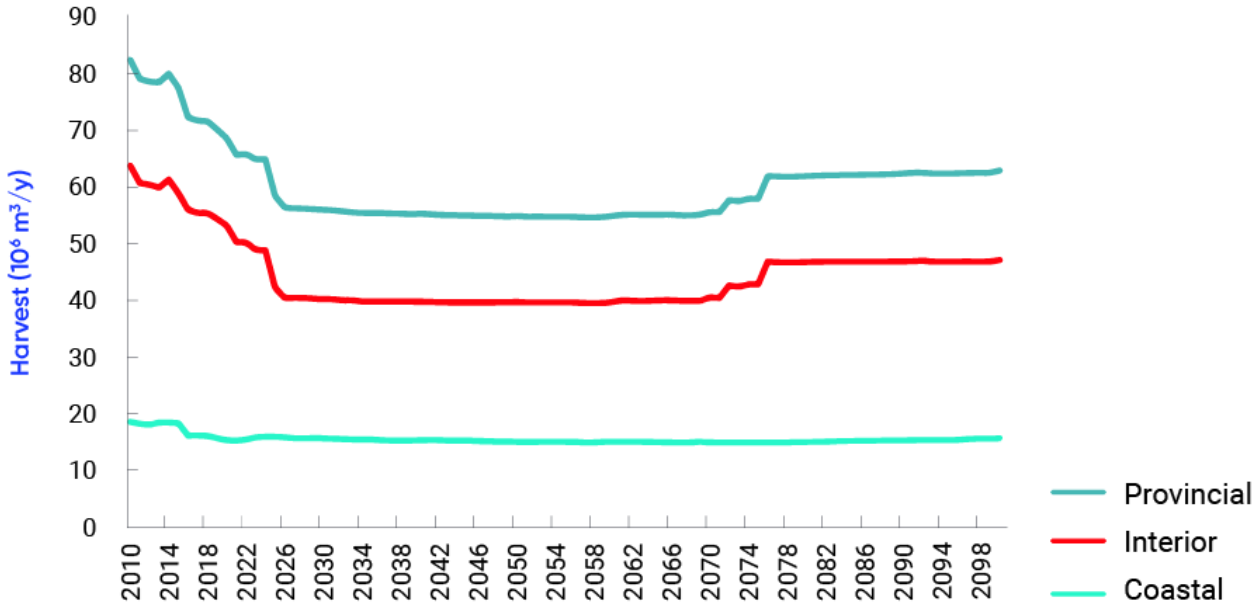

Figure 5.9: Provincial timber supply forecast to 2100, including data specific to B.C.'s interior and coastal regions. This analysis projects decreases in timber supply to about 58 million cubic metres per year by 2025, due to mortality caused by the Mountain Pine Beetle epidemic. The forecasted timber supply increases to 65–70 million cubic metres per year in 2075, although this does not account for potential impacts of climate change on tree survival and growth or for increases in disturbances. Source: Government of B.C., 2018c.

Longer-term changes in forest productivity and structure will arise as the geographic distribution of ecosystems shift in response to changing climate conditions. Changes in temperature, precipitation patterns and other climate variables may mean that plants and animals in any given area are exposed to conditions outside of their optimal climate. By 2050, climates typical of grasslands, dry interior forests and moist continental cedar-hemlock forests will expand substantially; the area of climates that are suitable for coastal rainforests will remain relatively stable; and the area of boreal, subalpine and alpine climates will decrease substantially (*see* Figure 5.10; Wang et al., 2012). Some climate regimes that currently do not occur in B.C. are likely to occur by the end of the century (Mahoney et al., 2018). This complicates the selection of species and provenances that are better suited to the anticipated future climate because there are no examples of desired tree species or provenances growing in such climates in B.C., although there may be examples in other jurisdictions.

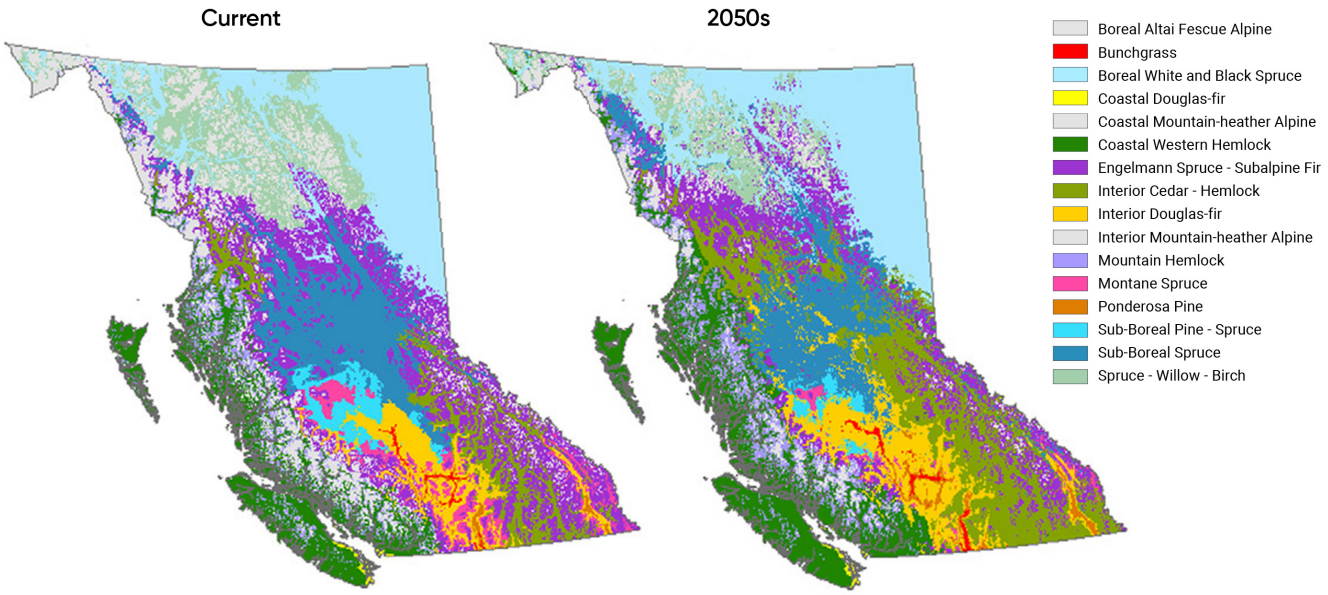

Figure 5.10: Distribution of the 16 biogeoclimatic ecosystem classification zones, for the period 2001–2009 and as projected for the 2050s based on consensus predictions with the best-model agreement among 20 climate change scenarios. Source: The University of British Columbia, 2022; Wang et al., 2012.

Ecosystem changes have significant implications for carbon storage. Increased air temperatures and a longer snow-free season increase the evaporative demand on vegetation and, combined with reduced summer precipitation in the central and southern parts of the province, increase the risk of drought, particularly at drier sites (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2016c; Spittlehouse, 2008). These changes are expected to reduce forest productivity, increase mortality, and increase susceptibility to insects and disease (Fettig et al., 2013). Productivity at cooler, higher elevation sites may benefit from warmer conditions (Dymond et al., 2016; Williamson et al., 2009). Analysis of climate change impacts on the annual forest carbon balance over the next century under multiple climate scenarios indicates that timber growing stock could decline by 26 to 62% over the 21st century, depending on changes in tree growth rates and annual area burned (Metsaranta et al., 2011). This analysis indicated that B.C.'s forests would be sources of greenhouse gases (GHGs) under many climate change scenarios, which could significantly impact the provincial carbon balance. As such, GHG emissions reduction and adaptation strategies would help to minimize climate change impacts on forests.

5.4.3 Enhancing forest resilience

The importance of climate change adaptation and forest resilience in Canada has been recognized for more than three decades (e.g., Wall, 1992; Pollard, 1991; Spittlehouse and Pollard, 1989), and has been a national priority since at least 2008 (Canadian Council of Forest Ministers, 2008). Provincial jurisdiction over forest resources and lands places the Government of British Columbia in a unique role for enabling a

framework in which different parties can work together in improving forest resilience to climate change. Addressing management goals and values, while considering the long-term risks associated with climate change at the local level, makes management plans more robust in the face of uncertainty and changing conditions. Proactively increasing species diversity at the time of planting can be a cost-effective climate change adaptation measure (Hoff et al., 2017; Dymond et al., 2015, 2014). Conservation of wildlife requires a vulnerability-adaptation framework based on species' individual vulnerability and exposure to climate change, the protection of refugia, the promotion of geophysical diversity, and habitat connectivity (Stralberg et al., 2019). A major challenge, however, is translating adaptation concepts into specific, tangible actions (Shannon et al., 2019; Hagerman and Pelai, 2018; Halofsky et al., 2018). It is important to include local knowledge as part of that process (Nelson et al., 2016). Examples of actions that enhance the resilience of forests and associated communities and infrastructure are presented in Case Stories 5.3 and 5.4.

Case Story 5.3: Climate-based seed transfer and climate change informed species selection in B.C.

Assisted migration can facilitate forest survival and growth under a changing climate (O'Neill et al., 2017; Pedlar et al., 2012; Peters, 1985). This involves reforesting harvest sites with seedlings of species and provenances that are suitable for survival and growth under a future climate, while still being able to withstand current climatic conditions.

The Climate-based Seed Transfer (CBST) project was initiated in 2012 to modernize the Province of British Columbia's seedlot selection system and to facilitate a wider use of assisted migration to help promote healthy, resilient and productive forests and ecosystems in a changing climate (O'Neill et al., 2017; B.C. Ministry of Forests, Lands and Natural Resource Operations, 2012a). CBST aims to define a target distance and transfer range for species to maintain the acceptable productivity. This seed transfer system takes advantage of genecological research, provenance trial data, fine-scale climate mapping, improved climate projections and genomics tools that assess the ability of a seed to succeed under future climate conditions (O'Neill et al., 2017), and also leverages benefits from strong science-policy connections (Klenk, 2015; Klenk and Larson, 2015). This is one of the first examples anywhere in the world where such a project has been developed and implemented. An example of CBST being implemented is the extension of the planting range for larch in B.C. (Klenk and Larson, 2015; Rehfeldt and Jaquish, 2010).

Another decision-support tool under development is the Climate Change Informed Species Selection (CCISS) tool (Mackenzie and Mahoney, 2020). This tool will project the suitability of different tree species for planting in ecosystem variants and site series, as described in B.C.'s Biogeoclimatic Ecosystem Classification system (Meidinger and Pojar, 1991). It is intended to be used in conjunction with the CBST tool. Whereas the CBST tool is used to determine the appropriate provenance or origin for the tree species, the CCISS tool will assess potential shifts in ecosystem units based on climate projections, which incorporate climate uncertainty. The CCISS tool also makes use of an ecologically derived rule set that summarizes which species are most likely to be suitable under projected future climate conditions.

5.4.4 Wildfire risk reduction

While wildfire is a natural part of the forest ecosystem cycle, climate change is driving increases in the size, frequency and intensity of wildfires, and is posing a threat to human life and infrastructure (*see* Sector Impacts and Adaptation chapter; Abbott and Chapman, 2018). The Preliminary Climate Change Risk Assessment for B.C. indicated with a high degree of confidence that severe wildfire is the highest-level climate risk for B.C. (B.C. Ministry of Environment and Climate Change Strategy, 2019). Wildfire science and policy in Canada are being challenged by the changing behaviour of fires and the need to account for the complex role that fire plays in forest ecosystems (Sankey, 2018). Growing awareness that historical fire suppression in some areas of B.C. is leading to unhealthy forests and ecosystems (Filmon, 2003), and increases in the Wildland Urban Interface and the cost of fire suppression, have resulted in a shift in focus towards prevention activities. Among the factors driving action are the costs associated with fire suppression, which have risen in recent years and are expected to continue increasing over time (Tymstra et al, 2020; Stocks and Martell, 2016).

Wildfire managers in B.C. and elsewhere have expressed a desire to move away from fire suppression and towards an approach that balances the need to rebuild the health and sustainability of forests with the need to reduce negative climate impacts to human lives and quality of life (Tymstra et al. 2020). One example is FireSmart, a longstanding program consisting of sets of practices that reduce risks to structures and surrounding areas, intended mainly for communities, fire regime restoration and targeted fuel treatments (FireSmart, 2018). Despite such guidance, there is relatively little information available to guide and prioritize investment decisions by forest professionals, communities and private land owners regarding wildfire reduction activities outside of private homes and community boundaries. Wildfire managers lack information about the actual costs and benefits of various treatments for reducing wildfire risk to the degree that is necessary for supporting the business case for investment of public funds (Sankey, 2018).

Case Story 5.4: Climate change adaptation and wildfire protection in a community forest

The Harrop-Procter Community Forest consists of 11,300 hectares of Crown Land on the south shore of Kootenay Lake, and has a mandate to practice socially and environmentally progressive forestry. The cooperative has four primary values: 1) protect domestic water; 2) maintain biodiversity; 3) create local jobs; and 4) protect communities from wildfire. The cooperative sells timber products from its mill in Harrop, has Forest Stewardship Council certification, and is actively engaged in community outreach.

Community wildfire protection is being addressed through a risk assessment and through the development of a management plan to reduce risk. Maps of ecosystem units, fuel loading and soil moisture regimes were used to assess the risk of fire to homes, water supply and biodiversity. Climate change scenarios were used to evaluate changes in soil moisture regime and fire risk. This assessment will aid in prioritizing areas for adaptive management. Management questions to consider include:

- How much forest to cut and how much fuel treatment can be done?
- Where to log first (e.g., drought-prone stands, poorly adapted species, wildland-urban interface, etc.)?
- Where to protect (e.g., headwaters, riparian, old growth, wildlife habitat, etc.)?
- How to log (e.g., opening size, use of partial cuts, type of fuel treatment, etc.)? and
- How to regenerate (e.g., which species, what provenance, and at what density)?

Source: Leslie, 2018

5.4.5 Progress on adaptation

There are several recent and ongoing initiatives in B.C. to advance adaptation in the forest sector. The provincial government has played a strong role in setting objectives for resource management and adaptation, developing a climate change strategy (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2015) and facilitating adaptation efforts led by other actors (e.g., licensees, First Nations, community forests, forest professionals). Examples of adaptation programs offered by the province include:

- The Community Resilience Initiative Program, which provides provincial funding for communities to develop community wildfire prevention plans and is administered by the First Nations Emergency Services Society (FNESS) and the Union of BC Municipalities (UBCM) (Government of B.C., 2021c);
- Climate action plans for each business area and forest region and pilot studies on assessing the risk of climate change to built infrastructure in forest regions, led by B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2015);
- The Forest Carbon Initiative, which takes into consideration how activities to enhance forest resilience can also serve to increase biological sinks (Government of B.C., 2021d).

Progress has been significant, but more needs to be done (Auditor General of British Columbia, 2018). Efforts have increased public awareness, supported new research into impacts and adaptation options, and produced information and tools for resource managers. Examples of relevant information and tools include climate summaries and adaptation extension notes for each forest region (*see* Box 5.4), and monthly historic and projected climate data in high spatial resolution. However, this has not yet translated into significant change within the industry, where practices remain largely unchanged and responses to date have been largely reactive (e.g., increased salvage logging following disturbances) (Williamson and Nelson, 2017).

Box 5.4: Adapting resource management to climate change: Tools for forestry practitioners

In 2016, the B.C. Ministry of Ministry of Forests, Lands and Natural Resource Operations produced Regional Extension Notes for each of B.C.'s eight forest regions that "…inform adaptation of natural resource planning and practices to climate change by providing best available information to resource professionals, licensees and Government staff engaged in: operational planning and practices under the *Forest and Range Practices Act* and other natural resource legislation; monitoring effectiveness of adaptation practices; assessing cumulative effects; and, preparing climate change action plans" (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2016a). Each note describes region-specific climate change projections, along with possible impacts on forest resources (e.g., ecosystems, tree productivity, hydrology, wildlife, fisheries). The notes also present adaptation strategies that reflect regionally important and best available information drawn from research and the input provided by regional specialists. The Regional Extension Notes are available here: https://www.for.gov.bc.ca/hfd/pubs/en.htm.

Professional organizations and associations have played an important role in promoting awareness and increasing understanding among their members and the public. For example, the Association of BC Forest Professionals has engaged in activities related to professional development and education, including undertaking province-wide surveys of its members on their needs related to understanding and adapting to climate change (Nelson et al., 2014). Work by non-governmental organizations includes the development of practitioner guides for climate change assessments and other tools to support adaptation planning by local managers (Pearce and Krishnaswamy, 2011). As elsewhere, monitoring and evaluation are key aspects of assessing progress on adaptation. A noteworthy example is the assessment of government responses to B.C. wildfires and floods (Abbott and Chapman, 2018).

5.4.6 Challenges

A key issue limiting progress towards adaptation in British Columbia's forest sector is the availability of information and resources at different scales for the different actors (Price and Daust, 2019), including those related to future timber supplies (*see* Box 5.5), and the capacity to act on that information (Shannon et al., 2019; Williamson and Nelson 2017; Nelson et al., 2016). Other challenges relate to the extent to which adaptation is integrated into policy and policy-making, and the institutional setting in which third parties prepare management plans and carry out activities on public lands.

Resource challenges relate to data and information, tools, as well as human and financial limitations. Issues with data relate both to accessibility and to spatial resolution, because operational decision-making benefits from local-scale data (Nelson et al., 2016). The information that is available through a range of databases and tools is often not in a form that the decision-maker can readily use (Price and Daust 2019; Halofsky et al., 2018). Although many decision-support tools exist, most do not yet fully account for climate change (*see* Box 5.5). Funding to aid provision of information in appropriate formats is a common concern, with solutions

likely to involve governments, professional associations and industry to increase the adaptive capacity of the forest management system (Williamson and Nelson, 2017; Nelson et al., 2016).

Box 5.5: Projecting future timber supplies

In British Columbia, the process for determining current harvest levels is largely based upon projections of future timber supply, which are typically modelled over a 100- to 200-year period. Built into those models are estimates of forest land area, inventory, growth and yield, as well as expected losses due to disturbance, all of which can be affected by climate change. To date, however, future climate change impacts are not considered in these models. Implicitly this assumes that these future impacts will remain constant, despite increasing evidence pointing towards greater incidence of disease and disturbance (Brown et al., 2013). The 2021–2025 Climate Change Strategy (in press) aims to addresses this deficiency.

The extent to which adaptation is integrated into policies and policy-making is often influenced by a range of institutional factors including, for example, allocation of rights, availability of public funding to manage risks and public attitudes towards alternative forest management strategies. Formal and informal policies can serve as either enablers or barriers to climate change adaptation. A commonly mentioned barrier is the lack of mandated use of climate change information and specific change scenarios in decision making (Price and Daust, 2019; Halofsky et al., 2018). Without relevant legislation, policies or operating procedures, resource managers cannot be assured that they will be supported in their adaptation decisions (Nelson et al., 2016). In some cases, this may preclude decision-makers from assessing or implementing adaptation strategies.

The traditional siloed approach to resource management reduces the ability to assess systematic risk (Williamson and Nelson, 2017), identify potential trade-offs and plan appropriate adaptation responses. Similar barriers sometimes exist between climate change adaptation and GHG emissions reduction initiatives, preventing or limiting the effectiveness of actions aimed at achieving either of those objectives (Williamson and Nelson, 2017). For example, B.C.'s Forest Carbon Initiative aims to reduce carbon emissions and increase sequestration through forest management. However, unless climate change risk factors are fully considered when assessing the long-term consequences of different GHG emissions reduction strategies, there is potential for proposed solutions to result in increased costs over time.

The roles of government and the forest industry are critical in forest management adaptation, where all industry activities are subject to government approvals, compliance and enforcement. In cases where industry operates on crown land, differences in perspectives between the government and the forest industry can affect how climate-related risk is assessed, and which industry incentives can reduce those risks (Hotte et al., 2016). From an industry perspective, one of the risks associated with climate change is the potential for increased management costs related to adaptation decisions made by government, which could become problematic for industry in the global market place (Williamson and Nelson, 2017).

In terms of economic analysis, fundamental challenges include the short time horizon of decision-makers and the impact of discount rates on evaluating the cost of future impacts (*see* Costs and Benefits of Climate

Change Impacts and Adaptation chapter). Both industry and government typically operate on the assumption of high discount rates and focus on short-term interests. Even where government may apply a lower social discount rate, this can still heavily discount the future, reducing the case for making larger or more proactive investments even where the risks are large and significant (Williamson and Nelson, 2017).

A final important challenge is the fact that the directly managed timber harvest land base is only about one third of the forest land base, which limits the applicability of many adaptation measures. For example, assisted migration in forest management will reduce the vulnerability of commercial tree species at selected sites. On the managed land base, however, less than 1% of land is harvested in a year (Government of B.C., 2018c); consequently, even over the next 50 years, assisted migration can only influence the direction of forest adaptation in a relatively small area of B.C. (Spittlehouse, 2005). Therefore, many forest species will have to adapt autonomously, which will affect ecosystem services and society. Of immediate concern is how to address the near-term risk of disturbance, such as fire, to human health and well-being in all forested regions of B.C. This risk perhaps provides the greatest challenge to management agencies in adapting to our changing climate in the short to medium term.

5.4.7 Conclusions

There is limited evidence of proactive adaptation within the forest industry in the province, suggesting a need for improved understanding of business risks and opportunities related to climate change. As a result of the vastness of B.C.'s forested area and the longevity of tree species, active forest management can influence forest adaptation only in selected areas, and much of the forested land will adapt through natural processes. Society will also have to adapt by adjusting expectations of and demands on forests.

5.5 Building a climate-ready agriculture sector is critical

Climate change is already impacting food production in British Columbia. Continued collaborative efforts across B.C. are needed to help advance adaptation in the agriculture sector.

In B.C., climate change impacts are already affecting the agricultural sector. These changes result from changing hydrological regimes; shifting range and life-cycle of pests, diseases and invasive species; and increasing wildfire frequency and intensity. Impacts occur across the food system, impacting production, processing and distribution. Adaptation programming is occurring to support the province's roughly 17,500 farms and includes efforts to create regional plans, to provide funding and to foster collaboration.

5.5.1 Agricultural climate change risks

B.C.'s agricultural sector employs approximately 63,000 people and produces over 200 commodities (B.C. Ministry of Agriculture, n.d.). In 2017, the sector generated approximately $14.2 billion in annual revenue (B.C. Ministry of Agriculture, 2018). This section discusses key risks for the sector, including flooding, reduced water availability, wildfire, and increases in pests, diseases and invasive species. For further discussion on agriculture and the national scale, *see* the Sector Impacts and Adaptation chapter.

5.5.1.1 Flooding and excess moisture

As described above, climate change is anticipated to intensify the hydrological cycle and increase precipitation variability regionally and seasonally (B.C. Ministry of Environment, 2016). Long-term projections show that these trends are expected to continue (Government of Canada, n.d.), with precipitation clustered temporally and longer drought periods, particularly for southern B.C. (Bonsal et al., 2019; Zhang et al., 2019; B.C. Ministry of Forests, Lands, and Natural Resource Operations, 2016b).

For agriculture, B.C.'s increasing seasonal precipitation presents challenges, such as contributing to spring freshet and winter runoff flooding intensification. Heavy precipitation and rapid snowmelt can cause erosion and nutrient leaching, impairing plant health and productivity (Fraser Valley Regional District, 2017). Following a severe drought or wildfire, increased precipitation may also cause erosion and site-specific flooding, resulting in crop and infrastructure losses (B.C. Ministry of Environment, 2016).

For agriculture, flood risk from winter runoff and spring thaw in the Fraser Valley is of particular concern as the area accounts for 38% of B.C.'s gross annual farm receipts (Government of B.C., 2018a). Within the Fraser Valley Regional District (FVRD), a major spring thaw flood event (1894 flood comparable) is estimated to result in $800 million in damages to producer assets and to have a $1.1 billion impact on the FVRD's agricultural economy (Northwest Hydraulic Consultants, 2016b). Potential agricultural costs in this scenario include damage to agricultural buildings and equipment, livestock mortalities and crop losses (Northwest Hydraulic Consultants, 2016b).

Flooding is also a significant agricultural production risk elsewhere in British Columbia. (B.C. Agriculture and Food Climate Action Initiative, 2019, 2016, 2014). Floods range from larger regional occurrences—e.g., the 2018 flooding of the Kettle and Granby Rivers (Yumagulova, 2019)—to small site-specific instances. Agricultural adaptation strategies range from regional-level action, such as enhancing dyking and natural infrastructure (e.g., forests, riparian areas, floodplains and wetlands), to farm-level action, such as planting riparian buffers, improving drainage systems and adopting flood-tolerant cropping or production systems. The extent to which these measures have been explored or adopted and the degree to which agriculture is represented in risk mitigation efforts vary regionally.

Sea-level rise and storm surges also pose flooding threats to coastal agriculture, through the risk of dyke breaches, soil salinization and farmland inundation (B.C. Agriculture and Food Climate Action Initiative, 2013). For example, in B.C.'s Delta region, most agricultural land is two metres or less above sea level, and existing protection mechanisms—dykes, seawalls and pumping stations—require costly upgrades for sea-level rise protection (Delcan Corporation, 2012). For dykes alone in the wider Metro Vancouver region, the estimated

cost is approximately $9.47 billion (Delcan Corporation, 2012) and the lost agricultural land from expanded or enhanced dyke systems is of concern.

Infrastructure and farming system upgrading and adaptation represent only one part of flood adaptation. Emergency response measures—including the Provincial Emergency Program (Government of B.C., 2016)—and recovery measures that emphasize rebuilding infrastructure to be more climate-resilient are important for reducing agricultural vulnerability.

5.5.1.2 Reduced water availability

The shifting seasonal distribution and intensity of precipitation pose additional challenges for B.C. agriculture. The frequency and intensity of extreme precipitation events will likely increase in southern B.C., and will be accompanied by rising summer temperatures and declining precipitation (B.C. Ministry of Environment, 2016). Less seasonal snow accumulation, hot and dry summer conditions, and reduced summer rainfall will influence the duration and frequency of seasonal drought (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2016b). Consequently, agricultural drought—when soil water deficiency causes plant water stress to negatively affect crop yield and productivity—is more likely (Government of B.C., 2018a). This type of drought occurred in southern B.C., with record breaking dryness, particularly in the South Thompson, Nicola, Similkameen and Kettle basins from late August through mid-October of 2017 (Government of B.C., 2018a). Recorded agricultural impacts of this drought include heat stress, accelerated crop maturation, reduced livestock feed, limited irrigation water supply, and reduced crop quality and quantity (Agriculture and Agri-Food Canada, 2017). These conditions also contributed to the severity of the 2017 wildfire season, which caused additional negative agricultural impacts, including losses to livestock, rangeland, forage, fencing and livestock infrastructure (Agriculture and Agri-Food Canada, 2017).

With drought conditions becoming more common across B.C., longer-term water shortages are likely (B.C. Ministry of Environment and Climate Change Strategy, 2019). With increasing shortages, there will be additional demand on relief and business risk management programming (e.g., the AgriStability Program, the AgriRecovery Framework, the Production Insurance Program, the Livestock Tax Deferral Program and the Western Livestock Price Insurance Program; Government of B.C. (2018a)). Governments and industry associations are also promoting preemptive measures to help farmers prepare for drought (e.g., through enhanced on-farm water storage and drought-tolerant cropping) and reduce water demand (e.g., through precision irrigation and regional crop water demand modelling).

5.5.1.3 Wildfire

Extreme warm and dry weather conditions enhanced the severity of B.C.'s recent wildfire seasons (Kirchmeier-Young, et al., 2019). In 2017, 1.22 million hectares burned, causing a $35 to $70 million agriculture capital and revenue loss (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018b). Then, in 2018, 1.35 million hectares burned in B.C.'s largest wildfire season on record (B.C. Wildfire Service, 2019). Ranching operations in particular were impacted by these two wildfire seasons, with record wildfire damage and loss of animals, farm buildings, fencing, forage crops and rangeland.

Additional impacts associated with wildfire include:

- the need to manage the logistics of relocating livestock and finding feed resources as the result of evacuation alerts and orders (B.A. Blackwell and Associates Ltd, 2018);
- decreased livestock health and productivity from smoke and evacuation transport (B.C. Agriculture and Food Climate Action Initiative, 2014);
- diminished crop production due to a lack of irrigation over multiple weeks for farm properties under evacuation orders;
- reduction of usable forage and pasture because of fire retardant contamination (B.C. Ministry of Agriculture, 2017);
- agri-tourism decline, particularly for Okanagan region vineyards (Abbott and Chapman, 2018; Government of B.C., 2018b);
- possible smoke taint in wine grapes, making them unfavourable for wine production (Noestheden, et al., 2018); and
- multi-year recovery challenges, such as rapid runoff from the loss of vegetation (Shakesby and Doerr, 2006) and changed soil structure, which can decrease soil productivity (DeBano, 1990) and increase erosion risks (Certini, 2005).

The B.C. wildfire seasons of 2017 and 2018 led to increased interest in reducing wildfire operational risks for agriculture. For example, the BC Cattlemen's Association, along with the Province, is piloting the use of grazing to reduce fine fuels—such as grass, pine needles and tree moss— with the aim of reducing wildfire risk near communities, and to allow ranchers to access new forage (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019b). Nevertheless, as hotter and drier summers occur, and as forest susceptibility to climate impacts increases (e.g., due to increasing pest populations), wildfire risk will continue to become more severe, with predictions of up to a 4% increase in annual area burned by 2050 (B.C. Ministry of Environment and Climate Change Strategy, 2019).

5.5.1.4 Pests, disease and invasive species

Climate change is shifting the latitude and altitude range, pervasiveness and frequency of insect pests, diseases and invasive species populations (Scholefield et al., 2017a). The distribution and lifecycles of pests, diseases and invasive species are being influenced by increases in annual temperatures, growing-degree days (GDDs), growing season length, winter/spring precipitation and extreme rain events, as well as drier summer conditions and warmer winters. The introduction of new pests, diseases and invasive species, the changes in number of generations possible in a single season, and the potential for reduced efficacy of management control measures have the potential to affect both crop and livestock producers (Beddington et al., 2012).

An example of a destructive pest identified in B.C.'s Fraser Valley in 2009 is the Spotted Wing Drosophila Fruit Fly (*D. suzukii*) (B.C. Ministry of Agriculture, 2014). This soft-skinned fruit pest lays eggs in ripe fruit (e.g., berries); consequently, high canopy humidity and ripe and over-ripe fruit create infestation risks. While the presence of this pest is not climate change-induced, milder winters and warmer summer conditions likely

increase the abundance and range of this pest, placing an elevated risk on small fruit and tree fruit crops in northern latitude regions (Langille et al., 2017). Studies undertaken in the Cariboo Region (i.e., Powell, 2018) and the Fraser Valley region (i.e., Scholefield et al. 2017a) have identified additional pests of concern that may shift in abundance and range as climate conditions change. Responses to these pests to date have been limited as there is opposition to long-term and landscape-level efforts in some jurisdictions (Scholefield et al., 2017a). Monitoring efforts in B.C. have tended to be relatively short-term and location-specific, focusing on select crops, pests, diseases or invasive species (B.C. Agriculture and Food Climate Action Initiative, 2015).

5.5.2 Agricultural adaptation programming

These climate change risks pose a compounding threat to agriculture in B.C. When considering the challenges together, there is unprecedented additional strain on agricultural profitability and existing emergency response and recovery systems (Donahue, 2014). In response to these risks, in 2013, the B.C. Ministry of Agriculture, Food and Fisheries partnered with the industry-led Climate and Agriculture Initiative BC (CAI)—formerly the B.C. Agriculture and Food Climate Action Initiative—to deliver adaptation programming.

CAI's mandate is to develop tools, knowledge and resources to enable adaptation in collaboration with producers, industry leaders, local governments, provincial agencies and academic institutions. For example, CAI developed the BC Agriculture and Climate Change Action Plan (B.C. Agriculture and Food Climate Action Initiative, 2010) and the Adaptation Risk and Opportunity Assessment Report Series in 2012. These publications helped to clarify the importance of collaborative and cross-disciplinary models for strengthening adaptive capacity (*see* Figure 5.11). Over 60 projects had been completed as of April 2020 through CAI's two main programs: the Regional Adaptation Program and the Farm Adaptation Innovator Program (FAIP).

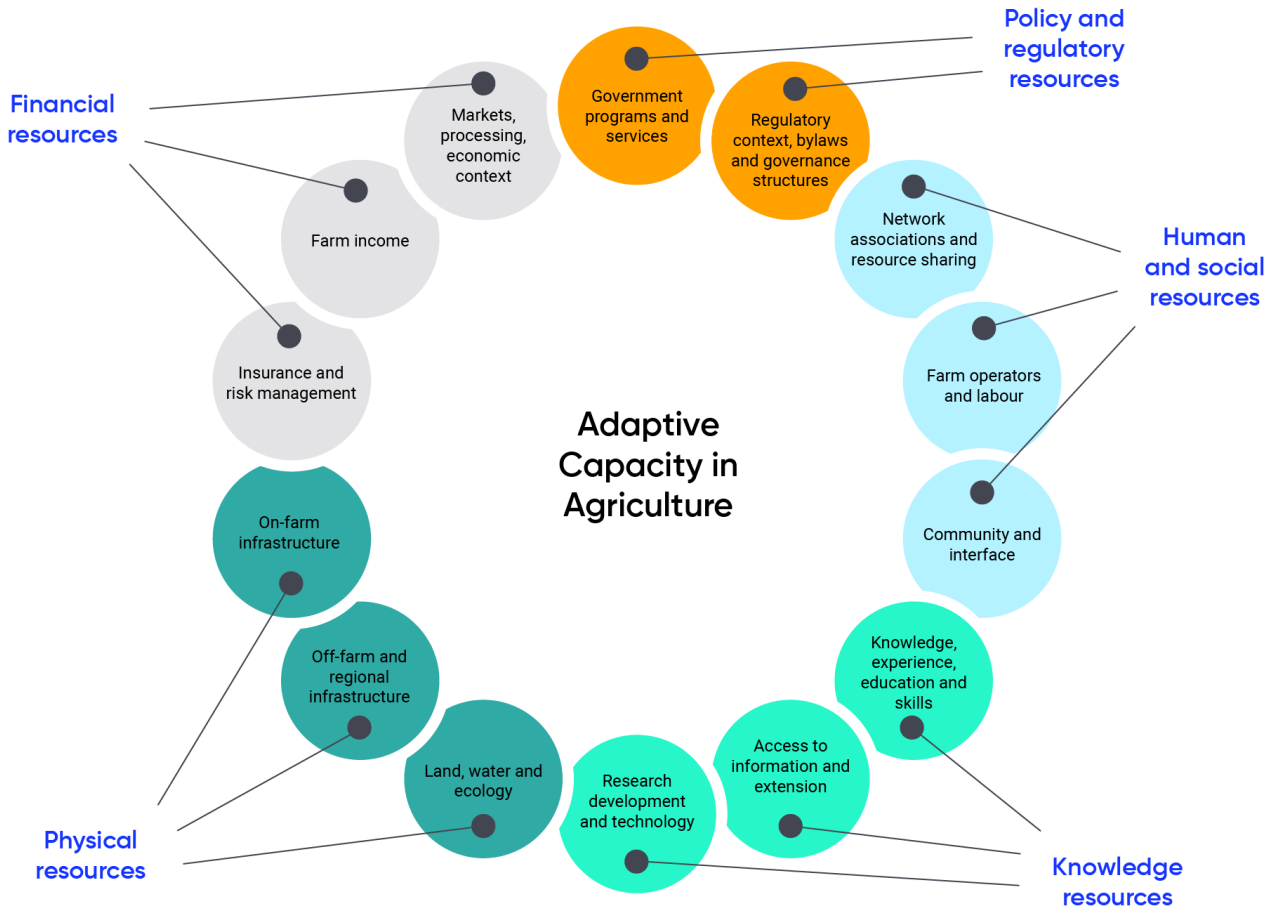

Figure 5.11: Factors influencing B.C.'s agricultural adaptive capacity. Source: Recreated based on B.C. Agriculture and Food Climate Action Initiative, 2012, Crawford and MacNair, 2018.

The Regional Adaptation Program has enabled regional adaptation planning processes that include seed funding and that bring together local governments, provincial agencies, agricultural organizations and producers. Between 2013 and 2020, plans were developed for eight regions of B.C.: Delta, Fraser Valley, Okanagan, Cariboo, Peace, Bulkley-Nechako and Fraser Fort-George, Vancouver Island and Kootenay-Boundary (B.C. Agriculture and Food Climate Action Initiative, 2010). These plans identify impacts, some of which are highly localized, requiring region-specific solutions, tools and resources. Other impacts are similar across regions, allowing projects to build on one another. For example, increasing wildfire risk was prioritized in the Cariboo (2014), the Okanagan (2016), Bulkley-Nechako and Fraser-Fort George (2019), and Kootenay-Boundary (2019) regional plans and a series of regional projects created guides and workbooks to aid farmers and ranchers with developing operational wildfire preparedness plans. The FAIP supports farm-level, multi-year applied research projects examining adaptation-focused farm practices or technologies that reduce weather-related production risks and/or increase new production opportunities (B.C. Agriculture and Food Climate Action Initiative, 2018). Projects range from an evaluation of insect (thrips) damage to potatoes

in a changing climate in the Fraser Valley, to the demonstration of adaptation practices for forage production in the Central Interior, to an evaluation of soil and water management practices for Sweetheart Cherry production in shifting climatically suitable growing locations in the Okanagan (*see* Case Story 5.5).

Case Story 5.5: Opportunities and barriers associated with B.C. cherry production

The climate component of crop suitability modelling for Sweetheart cherries (*Prunus avium L.*) over the past five decades in the Okanagan region has shown a significant expansion in northern and higher elevation areas due to decreasing frost (*see* Figure 5.12). Building on this climate suitability modelling, Nelson (2018) investigated whether the soil microbiological conditions were also suitable for establishing Sweetheart cherry orchards in locations that matched climate suitability. The study found that soils in newly established orchards were more biologically suitable than older orchards, highlighting the importance of managing soil health in established orchards (Munro et al., 2020). Building from these findings, the next FAIP project (2019–2023) focuses on cherry water management practices (B.C. Agriculture and Food Climate Action Initiative, n.d.) given increasing regional water scarcity (Neilsen et al., 2018), a potential limitation for orchard expansion. This project primarily investigates whether post-harvest deficit irrigation practices—the reduced application of water following fruit harvest—in the autumn can reduce water demand for cherry orchards, without compromising fruit quality and the long-term health and vigour of the orchard.

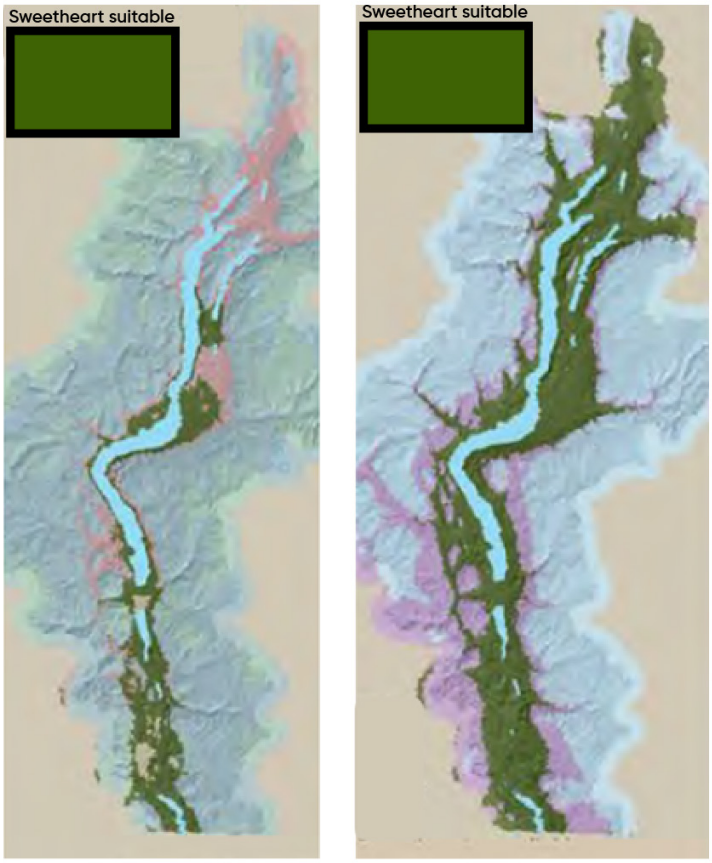

Figure 5.12: Expanding soil suitability for sweet cherry production in the Okanagan Valley comparing data for 1961–1970 (left) with data for 2001–2010 (right). Source: Based on models published in Neilsen et al, 2017.

5.5.2.1 Agricultural Climate Adaptation Research Network (ACARN)

ACARN, launched in 2017, acts as a provincial hub to foster collaborative and strategic agricultural adaptation research and extension in British Columbia (B.C. Agricultural Climate Adaptation Research Network, 2018). Actions include hosting educational programming and annual provincial workshops for knowledge mobilization and collaboration among researchers, producers, government and agriculture professionals. With strong linkages to FAIP and other climate change-focused projects led by its members, ACARN is bringing researchers together to strengthen awareness of current research and to facilitate data-sharing. The long-term success of ACARN depends on strengthening linkages between industry groups and researchers to prioritize research that addresses industry needs, improving the ability of researchers to collaborate across institutions, disciplines and regions, and securing long-term funding (B.C. Agricultural Climate Adaptation Research Network, 2018).

5.5.3 Conclusion

Agricultural adaptation is an emerging provincial priority. Through federal and provincial funding, B.C. has initiated programing to identify climate change risks and to implement priority adaptation actions. Recent wildfires, floods and regional water shortages have accelerated the need for adaptation and emergency management; however, gaps in planning, implementation and evaluation still exist. Limited financial and human resources are allocated to climate change adaptation within governments, and there has not yet been wide-scale adoption of agricultural climate change considerations, planning tools and initiatives by governments and producers (Auditor General of British Columbia, 2018). Continued collaborative efforts at the farm, regional and provincial levels that are multi-temporal and cross-sectoral would help to advance agricultural adaptation in the province.

5.6 Adaptation continues to advance in B.C.

Climate change adaptation activities—including efforts focused on implementation—are present across most sectors and settings in B.C. This work continues to mature, supported by improved access to climate data, decision-support tools, funding, supportive institutions and collaboration. However, significant gaps remain and it is unclear whether current and proposed efforts will be sufficient given the extent of the risks faced and the costs of implementation.

The climate change adaptation field in B.C. has continually progressed, partly due to the impacts of increasingly extreme weather events and a growing understanding of both short- and long-term risks. Local and regional governments play an important role in convening planning processes and implementing projects, but capacity constraints still exist across B.C. The provincial government and public sector organizations are active contributors to climate change adaptation, and significant financial resources are required to drive implementation at the provincial scale. A wide range of B.C. professional practitioners, private sector organizations, NGOs, boundary organizations and academic groups are contributing to adaptation, either explicitly or as part of other initiatives. Although adaptation is advancing, further efforts are needed to deal with the growing risks.

5.6.1 Introduction

This section discusses the important role that various levels of government play in advancing climate change adaptation in B.C. (for an Indigenous-focused discussion, *see* Section 5.2). It also includes a discussion of existing resources and challenges for the adaptation field generally, and the role that non-government actors play in advancing adaptation.

5.6.2 Municipal and regional governments

B.C.'s municipal, regional and Indigenous governments are important drivers of climate change adaptation (Kovacs et al., 2020; Yumagulova, 2020; Auditor General of British Columbia, 2018; Vadeboncoeur, 2016). They are well placed to identify local vulnerabilities and address equity issues (*see* Box 5.6), implement appropriate actions and integrate disaster risk reduction and climate change adaptation (The Expert Panel on Disaster Resilience in a Changing Climate, 2022).

The level of local government adaptation activity varies across B.C. Early adopters at the local government level included the following: the cities of Vancouver (which developed Canada's first official municipal adaptation plan in 2012), Richmond, Prince George, Surrey and Kimberley; the Corporation of Delta; the Districts of Elkford and Saanich; and the Cowichan Valley Regional District, with many more entities now engaged in adaptation. Some include adaptation in existing plans and operations, while others have developed standalone adaptation plans, and some are beginning to advance to implementation. Many local government networks convened by partner organizations are also playing a key role in advancing adaptation in British Columbia. Regional governments, including Metro Vancouver, the Cowichan Valley Regional District and the Capital Regional District, have also developed adaptation planning, with Metro Vancouver developing a comprehensive vision for climate action by 2050 and embedding regional green infrastructure planning as a low-carbon resilience approach into the upcoming Regional Growth Strategy refresh (Metro Vancouver, 2018).

However, local governments still face numerous challenges, including a lack of locally specific data and knowledge, inadequate human and financial capacity, and a need for more supportive policies at the provincial level (Auditor General of British Columbia, 2018) (*see* section 5.2 for a discussion of First Nations challenges). Leadership shown by staff and elected officials, backed up by robust plans, policies and systems (e.g., infrastructure, ecosystems), is essential to motivate planning efforts (Birchall and Bonnett, 2021). Recently, recommendations were co-developed by the Province and the Union of B.C. Municipalities' (UBCM) *Green Communities Committee Adaptation Working Group* to support municipal government climate change adaptation efforts (Government of B.C., 2020a; UBCM, 2020). These included committing to ensuring local governments had the tools and resources needed to complete climate risk assessments and to adopt adaptation plans by 2030.

Box 5.6: Equity

Exposure and susceptibility to hazards are disproportionately skewed towards populations that have been placed at higher risk, resulting in asymmetrical impacts. The cascading nature of these crises and the risks that they pose underscore the intersectional nature of income and health disparities, environmental racism, the legacy of colonization, and other sources of vulnerability in our communities (*see* Health of Canadians in a Changing Climate Report). It is crucial to recognize and identify the compounding impacts of climate change and inequality in public health and other emergencies in order to develop effective, equitable solutions and to identify opportunities for preventative approaches (ACT, 2020a). Acting to address these issues, and to promote equitable outcomes through respectful engagement and resourcing, can help to reduce risk, alleviate pressure on critical systems during and after extreme events, and achieve co-benefits such as improved health and cultural and economic opportunities.

The City of Vancouver's VanPlay Parks and Recreation Services Master Plan models a deliberate focus on equity, inclusion, and access to parks and recreation, with co-benefits for reduced urban heat and flooding, human health and active transportation (Harford and Hunter, 2021). Similarly, engagement conducted by the Climate Action Secretariat sought to ensure that assessments of risk to Indigenous communities were produced by Indigenous community members in a culturally sensitive manner (Indigenuity Consulting Group Inc., 2020).

5.6.3 Provincial government

The Ministry of Environment and Climate Change Strategy's Climate Action Secretariat (CAS) is responsible for coordinating a government-wide approach to adaptation in B.C. (Auditor General of British Columbia, 2018). Their work is complemented by adaptation work in a number of other ministries, including the Ministry of Forests, Lands, Natural Resource Operations and Rural Development, and the Ministry of Agriculture, as well as the Ministry of Transportation and Infrastructure, and Emergency Management B.C. (EMBC), the latter stressing the urgency of addressing climate change in their disaster-mitigation funding offerings (Emergency Management B.C., 2021).

British Columbia was one of the first jurisdictions in Canada to publish a provincial-scale climate change risk assessment (B.C. Ministry of Environment and Climate Change Strategy, 2019). This semi-quantitative analysis was done to help better understand and address the risks the province is facing. It assesses the likelihood and consequences of 15 potential climate risk events across multiple sectors at the provincial scale, considering risk in the context of events that would constitute a level of emergency requiring the provincial government to respond. The province is currently exploring ways to uphold Indigenous values in its climate risk assessments (Government of B.C., 2020b). For a list of completed and planned activities, *see* the *Managing Climate Risk* table in the Government of British Columbia's 2020 Climate Change Accountability Report (Government of B.C., 2020a). Provincial leadership is essential in supporting a harmonized and strategic approach to adaptation across the province, including in coordination with the federal government.

Hazard, Risk and Vulnerability Analyses (HRVA) are mandated by the provincial Local Authority Emergency Management Regulation, cover all hazards and usually have a five-year time horizon (EMBC, 2020). HRVAs in B.C. typically consider extreme weather, but have not rigorously included climate change to date (e.g., Bowen Island Municipality, 2018). An updated HRVA tool being developed by the Province will encourage users from local and regional governments and First Nations to think not only about how the climate will change in the future, but also how today's climate is already different from that of the past— thus cautioning against an overreliance on solely historical climate data.

5.6.3.1 Public sector organizations

The Province provides the mandates for Public Sector Organizations (PSOs)—including school districts, health authorities, post-secondary institutions and Crown corporations—that operate critical infrastructure and large-

scale assets throughout B.C. communities, and thus play an important role in managing future climate risks. Impetus for adaptation action across PSOs ranges from internal voluntary measures to research projects and regulatory requirements. For example, amendments to the *Climate Change Accountability Act*, SBC 2007, c. 42, in 2022, enable the Province to establish requirements for PSOs related to reporting on climate risks and for the management of climate risks to public sector buildings, including considerations in the capital planning and approval process, and in climate risk reporting requirements that are comparable to existing public sector reporting on GHG emissions.

Risk assessments, planning, piloting and implementation are occurring across several PSOs; examples include BC Housing's Mobilizing Building Adaptation and Resilience (MBAR) project (B.C. Housing, 2020), which seeks to increase knowledge and capacity among building owners and occupants, and B.C. Hydro's work to understand current and future risks that extreme weather creates for its assets and services (B.C. Hydro, 2019b, 2019c).

5.6.4 Adaptation resources and challenges

Researchers, NGOs, practitioners and professional associations are also advancing adaptation in B.C. These organizations and individuals intervene at multiple points in the adaptation spectrum and have created many adaptation-focused, decision-support planning tools for a variety of sectors (e.g., ACT, 2020b; Government of B.C., 2020a).

Localized historical and projected climate data can be extremely useful to planning, decision making and implementation under a changing climate, across a variety of scales. Various helpful resources now offer modelling and projections for climate change impacts across B.C. under a range of scenarios. Some of these resources have been produced by the Pacific Climate Impacts Consortium (PCIC), a regional climate service centre at the University of Victoria and partner of the new federal Canadian Centre for Climate Services that aggregates historical and projected climate data being produced across the country and offers free online support services (Capital Region District, 2017; Cowichan Valley Regional District, 2017; Pacific Climate Impacts Consortium, 2017a, 2017b; Metro Vancouver, 2016). B.C.-focused data have also been created by provincial government staff (e.g., Foord, 2016), local governments, not-for-profits, and federal initiatives. For example, Living Lakes Canada's Columbia Basin Water Hub, which provides access to open data and research that are useful in the beginning phase of adaptation planning (Columbia Basin Water Hub, 2021). These local resources are supplemented by national resources like www.climatedata.ca and https://climateatlas.ca.

Resources are being developed using this data with the goal of inspiring action and enabling decision making. For example, a 2018 CBC podcast series called 2050: Degrees of Change explored projected climate changes for B.C., and provided examples of adaptation in several sectors (CBC Listen, 2017). Some existing online resources aggregate these new resources for ease of use, including the ReTooling for Climate Change website (BC Regional Adaptation Collaborative, 2022) and an online Climate Adaptation Tools Inventory (Government of B.C., 2021e).

Other organizations are engaged in capacity building for BC professionals. Royal Roads University's Adaptation Learning Network (Adaptation Learning Network, 2020) aims to increase professionals' capacity for climate change adaptation and is supported by B.C.'s Climate Action Secretariat and Natural

Resources Canada. Similarly, Engineers and Geoscientists B.C. provides guidance to its members on how to incorporate climate change adaptation into their practice (Engineers and Geoscientists British Columbia, 2020). To support designers, PCIC has produced a set of future weather files that are useful for designing energy-efficient, climate-resilient infrastructure and buildings (Pacific Climate Impacts Consortium, 2020). The penetration and impact of the above knowledge products and decision-support tools have not been empirically studied in B.C., but the adaptation field is clearly active and working to address the earlier parts of the adaptation spectrum.

Funding is often identified as a barrier to action on adaptation (Bednar et al., 2018), and governments, foundations and non-profits in B.C. are increasingly offering a variety of economic supports to facilitate aspects of action on adaptation. There is a substantial amount of federally funded activity locally, including at the level of regional districts and First Nations governments. However, this funding has primarily supported planning activities, and may not be positioned to allow the sustained level of cross-sectoral collaboration thought to be effective for adaptation planning.

The next steps in the adaptation process, such as implementation and monitoring and evaluation (M&E), are still largely nascent at all scales, partly because M&E tools are not yet well-developed, and partly because the cost of implementation often requires extremely expensive infrastructure upgrades or retrofits. For example, a 2012 study commissioned by the Province found that the cost to upgrade coastal protection to one metre of sea-level rise (SLR) in the Lower Mainland would be $9.5 billion (B.C. Ministry of ForestsLands and Natural Resource Operations, 2012b). It is unlikely that government funding will be sufficient to address the scale of action needed to address climate risk, and public-private partnerships (PPPs) will be required (ACT, 2015); however, there are as yet few examples of adaptation-related PPPs in BC. Recent advances in cost-benefit research could support decision-making efforts, for example by demonstrating to decision-makers that cost-benefit ratios for adaptation actions are very favourable (Boyd and Markandya, 2021).

Those involved in adaptation planning are increasingly motivated to consider the GHG implications (positive and negative) of their proposed actions (Nichol and Harford, 2016). Much of this work is occurring under the banner of low-carbon resilience, which emphasizes the need to reduce both emissions and vulnerability to climate change impacts (Nichol and Harford, 2016). If not strategically planned, these efforts risk increasing emissions and reducing the effectiveness of adaptation, as well as wasting resources and time. A number of pilots are under way that are refining concepts and empirically validating the low-carbon resilience approach, as well as exploring how “multi-solving” plays out in local contexts (ACT, 2020c).

It will be important to refine governance regimes relating to adaptation in the province. This refinement applies between First Nations and all levels of non-Indigenous government, horizontally (e.g., between the Ministry of Health and MOECC), as well as vertically. The B.C. Office of the Auditor General has identified the need for cross-agency coordination in planning for climate change adaptation in British Columbia (Auditor General of British Columbia, 2018). There is likely a role for the federal government to convene provincial, territorial, Indigenous and municipal governments to co-develop a more coordinated approach to governing adaptation (Sawyer et al, 2020).

5.6.5 Conclusions

As the climate change adaptation field matures in B.C., the focus is evolving from assessing risks and developing plans to also implementing adaptation and the beginnings of monitoring and evaluation. Important barriers and challenges still remain across the adaptation spectrum (Auditor General of British Columbia, 2018; Bednar et al., 2018), as most local governments and sectors still do not have a good understanding of all the climate change risks that they face, nor do they have the capacity to respond to them. While a systematic assessment has not been conducted of whether current and proposed levels of adaptation activity are likely to be sufficient for the increasing risks faced in B.C., it appears likely that more effort, collaboration and resources will be required.

5.7 Moving forward

5.7.1 Knowledge gaps

The assessment of current knowledge presented in this chapter reveals knowledge gaps across the adaptation spectrum.

Although B.C. has a history of providing access to climate projections, there is a need to update the networks of data collection instruments that collect climate data in the province (e.g., temperature, precipitation, snow depth). For example, the sparsity of monitoring stations in the northern regions of the province and at high elevations can make locally specific planning more challenging. There are also gaps relating to hydrometric and groundwater monitoring in the province (Auditor General in British Columbia, 2018). There is also a need to better understand shifting ranges of various pests, diseases and invasive species that affect B.C. ecosystems and natural resource sectors (Scholefield et al., 2017a).

Many locations in the province still do not have up-to-date flood maps, and many point to a lack of resources and capacity as primary reasons for lacking these maps (British Columbia Auditor General, 2018; B.C. Real Estate Association and University of British Columbia Okanagan, 2021). The representation of agriculture and prioritization of agricultural values in floodplain planning constitute a current knowledge gap.

There is also a need to better understand compounding hazards and cascading impacts, both of which can be challenging to achieve due to the dynamic interplay between multiple hazards and impacts. For example, a study of the infrastructure costs associated with future projections for B.C. did not examine cascading impacts, and thus potentially underestimated impacts and costs (e.g., Ryan et al., 2021). Similarly, although risk assessments are becoming more common, there is a growing need for after-action reports that summarize impacts (e.g., B.C. Hydro, 2019c) across scales, including communities, regions, and the entire province.

As with other sectors and regions, there is a need for contextual information about costs and benefits, the costs of inaction and expected reasonable returns on investments for adaptation initiatives (*see* Costs and

Benefits of Climate Change Impacts and Adaptation chapter). Although national figures are useful (Sawyer et al., 2020; e.g., Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020) and some provincially relevant costs exist (e.g., for dyke improvements in the lower mainland), more contextualized information is needed. It is also important not to overlook costs that are difficult to quantify in economic terms (Sawyer et al., 2020).

Monitoring and evaluation strategies need to continue to be developed and adopted alongside progress in implementation, especially with activity occurring across sectors and scales. Limited guidance exists for this task (e.g., EPCCARR, 2018), and there is a need to determine appropriate scales, geographies and objectives for M&E in B.C.

5.7.2 Emerging issues

This assessment of the current knowledge of climate change impacts and adaptation in B.C. highlights several emerging issues that will influence the development of the adaptation field.

The atmospheric river event and subsequent floods and landslides in November 2021 demonstrate the tension between emergency management, which is reactive by nature, and proactive adaptation. The financial resources required to rebuild damaged infrastructure are extensive and will very likely diminish—at least in the short term—the resources available to fund various proactive initiatives identified in B.C.'s Climate Preparedness and Adaptation Strategy. The unprecedented nature of this event, along with the heat event in June 2021, is still of concern in that B.C. is experiencing an inability to keep pace with the rate of change. However, it is also possible that these events can provide an impetus for action. For example, there is potential that lessons learned from the November 2021 flooding could inform and help stimulate revisions for improved flood risk management in B.C.

Another emerging issue is innovation in how financing is secured and distributed in order to meet the often large needs across sectors and scales. Examples of areas being explored include how municipal revenue could be decoupled from development charges and property taxes, and how new sources of income could help to alleviate the disproportionate burden of costly climate impacts and responses (ACT, 2015).

B.C. has introduced legislation to ensure that its laws are brought into line with the United Nations Declaration on the Rights of Indigenous Peoples (Government of B.C., 2020d), and that the essential role of Indigenous leadership and knowledge in adaptation is increasingly recognized (The Expert Panel on Disaster Resilience in a Changing Climate, 2022). However, the potential of these efforts are only beginning to be glimpsed. For instance, the Tsleil Waututh Nation is leading a storm water planning process that focuses on the health of Burrard Inlet and is based on their community's values and traditional ways of knowing. This process serves not only to increase climate resilience, but also to strengthen Indigenous rights and self-determination. There is an emerging need for centering Indigenous leadership and creating just and fair adaptation governance regimes in connection with adaptation in B.C.

Reconciliation is imperative across all sectors and settings in B.C. For example, the impact of climate change on Indigenous food security and food sovereignty is being studied by Indigenous organizations (e.g., First

Nations Health Authority, 2022), and the role that agricultural climate adaptation plays in reconciliation is increasingly a topic of focus for the Government of British Columbia.

5.8 Conclusion

British Columbia faces significant challenges as the climate continues to change. These changes impact all regions and multiple sectors of the province, and the longer-term risks to hydrology, forestry, agriculture and communities are significant. Indigenous Peoples and communities are uniquely impacted and are increasingly leading climate change adaptation initiatives at various scales. Centering and supporting Indigenous leadership and knowledge systems are essential, and collaboration with governments and partners is possible only when it is co-created with Indigenous Peoples in ways that protect and strengthen Title, Rights, and jurisdiction.

Managing flood risk in B.C. will continue to be a priority as hazards from riverine, coastal and urban flooding intensify. Although some strategies and governance processes are in place to reduce these risks, a number of key challenges exist that represent urgent areas of action given the level of risk faced.

B.C.'s vast and important forests are exposed to a number of significant climate-sensitive hazards, many of which will likely lead to changes in forest productivity, wildlife habitat and ecosystem services. Although the forest sector has long been adapting to climate change in the province, more proactive adaptation would help to ensure the continued health and productivity of B.C.'s forests.

Agricultural adaptation is an emerging provincial priority in B.C., and recent extreme weather events have accelerated the need for wide-scale adaptation and emergency management, and have highlighted gaps in preparedness. Continued collaborative efforts at farm, regional and provincial levels will likely advance agricultural adaptation in the province.

Local and regional governments and First Nations continue to be important drivers of adaptation implementation. The province and public sector play an important role in leading and supporting adaptation efforts across multiple scales, supported by researchers, practitioners, NGOs and professionals.

Further action is required across multiple sectors and scales to meet the challenges that are likely to emerge as the climate changes. However, accelerating widespread implementation will be challenging. Significant resources will be required to create a level of action that is commensurate with the risks that British Columbia is facing. It will also be difficult, but important, to establish a baseline of risks and vulnerabilities, to evaluate the effectiveness of adaptation efforts, and to monitor improved resilience to the climate risks described throughout this chapter.

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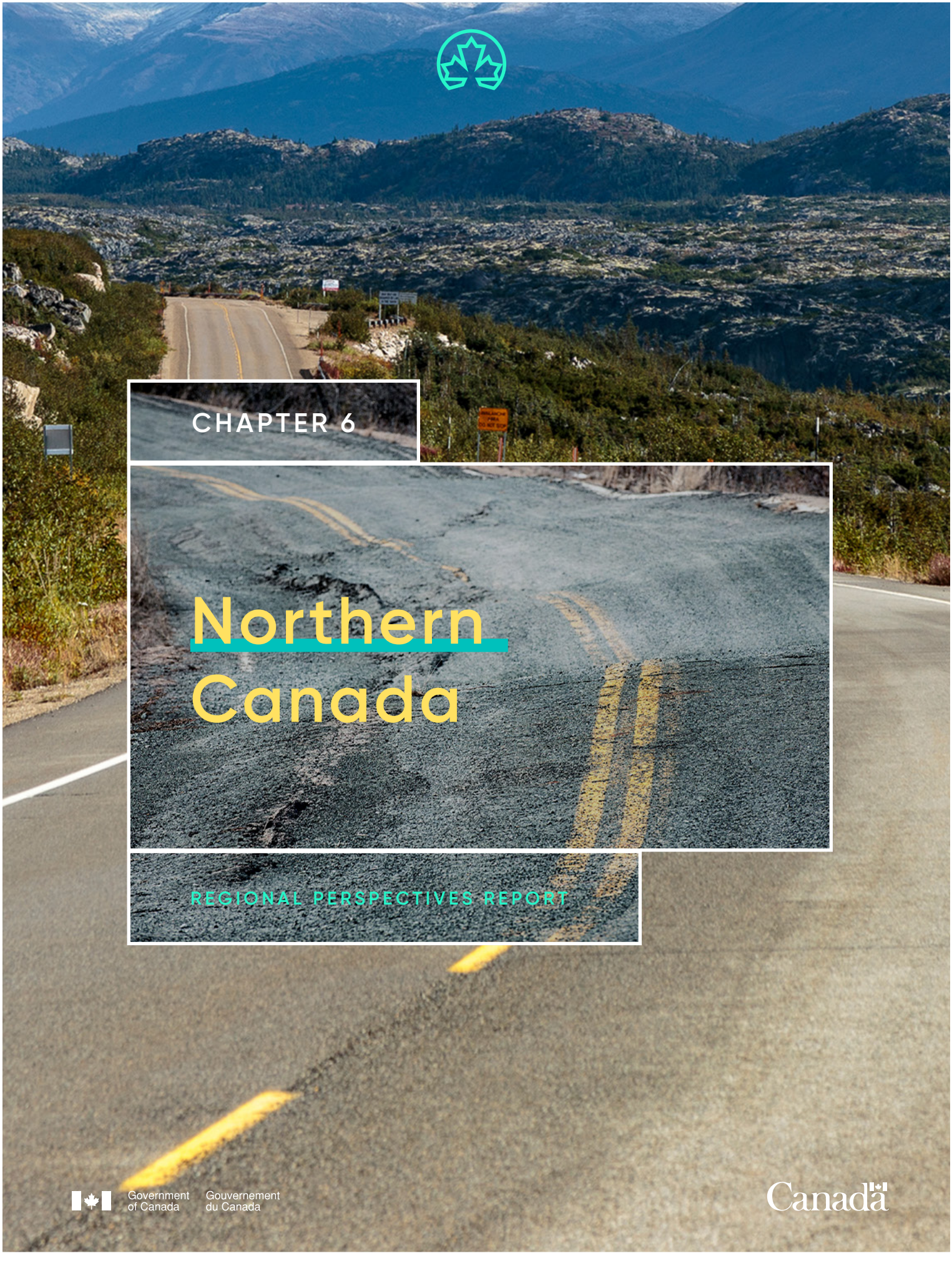

CHAPTER 6

Northern Canada

REGIONAL PERSPECTIVES REPORT

Government of Canada
Gouvernement du Canada

Canada

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Key Messages

Climate change is severely impacting northern landscapes and ecosystems (*see* section 6.2)

Climate change is producing severe, and in many cases irreversible, changes to northern landscapes and ecosystems. Northerners are trying to understand the limits of ecosystem resilience and our capacity to adapt to these changes.

Health impacts are intensifying and amplifying inequities in the North (*see* section 6.3)

Climate change is negatively impacting the health of Northerners, amplifying existing inequities and access to healthcare. Locally appropriate, culturally relevant resources and programming, co-created by local communities in partnership with other organizations, are critical to support climate-sensitive physical and mental health outcomes.

Safe travel in the North is threatened by climate change (*see* section 6.4)

Climate change is increasing risks to safe travel in the North, but drawing from different types of knowledge is helping to reduce these risks.

Northerners are leaders and innovators in climate change adaptation (*see* section 6.5)

Innovative approaches to governance, policy and development are addressing social inequities and opening pathways for collaborative and inclusive climate change adaptation.

Recognizing inherent capacity is key to building climate resilience (*see* section 6.6)

Organizations and individuals that recognize and embrace the inherent capacity of northern communities to adapt are key players in the pursuit of climate resilience.

Preface: A message about urgency from the Coordinating Lead Author

Together, the authors and advisors who helped craft this chapter represent decades of lived experience in Canada's North. I would not have been able to complete this chapter without their thoughtful guidance. We are in their debt for the support that they provided.

As the key messages in this chapter demonstrate, northern adaptation to climate change impacts is a lively and complex topic. However, some important messages are not easily conveyed; foremost amongst these is the urgency for action on so many fronts.

I am alarmed by the changes that we are witnessing here, and cannot adequately express the need for urgent action. Northerners are indeed taking action to adapt and are determined to continue doing so. Still, this chapter underscores that building resilience in the North means much more than anticipating the future and changing an existing or planned course of action. Addressing urgent societal issues—such as housing shortages, education, food security and culturally appropriate health and wellness—is deeply intertwined with efforts to build resilience to climate change. I have heard it stated, "How can you worry about climate change when you're hungry?"

At the same time, I fear that adaptation efforts will encounter unmovable limits. The magnitude of projections for temperature increase, sea-level rise, and ice and permafrost loss for the next century will force us to consider the unthinkable—for example, abandoning homes and traditional territories, moratoria on harvesting traditional foods, and travelling exclusively by air rather than on land or sea. Currently, many of these "solutions" are almost taboo—they are too difficult to consider, but they represent possibilities in the coming decades. Northern Indigenous cultures have shown intense resilience over centuries. Holistic knowledge passed through traditional and cultural practices will continue to ensure a level of cultural well-being, but climate change has joined stressors such as social inequity, the legacies of colonialism and environmental issues only partially related to climate change (such as northern contaminants) as a continual and pervasive threat.

The North will be unable to adapt alone. Paying for the costs of climate change is everyone's responsibility; they cannot be borne solely by Northerners. Similarly, there is an urgent need to improve access to the knowledge, solutions, innovation and creativity of Canadian and international experts who are willing to work alongside us as equal partners. I urge Canadians to use the key messages in this chapter to compel urgent adaptation action, but I also call for bold conversations that acknowledge social inequity and the limits of adaptation.

Our North depends on it.

Bronwyn Hancock, PhD

6.1 Introduction

In a region where much of society is deeply tied to the natural environment, changes to the land have the potential to deeply impact the people who live there and who depend upon the land. Many Northerners report that their livelihoods, culture, relationships with the land, and mental health and well-being are being impacted by environmental changes (Kuzyk and Candlish, 2019; Meredith et al., 2019; Bell and Brown, 2018; Stern and Gaden, 2015; Berry et al., 2014), including climate change (*see* Figure 6.1). While the adaptive capacity of Northerners, especially Indigenous Northerners, has allowed them to be resilient to change for generations (Pfeifer, 2020), the pace of change to which we must adapt has accelerated and is outpacing existing adaptive capacity (Ford et al., 2014).

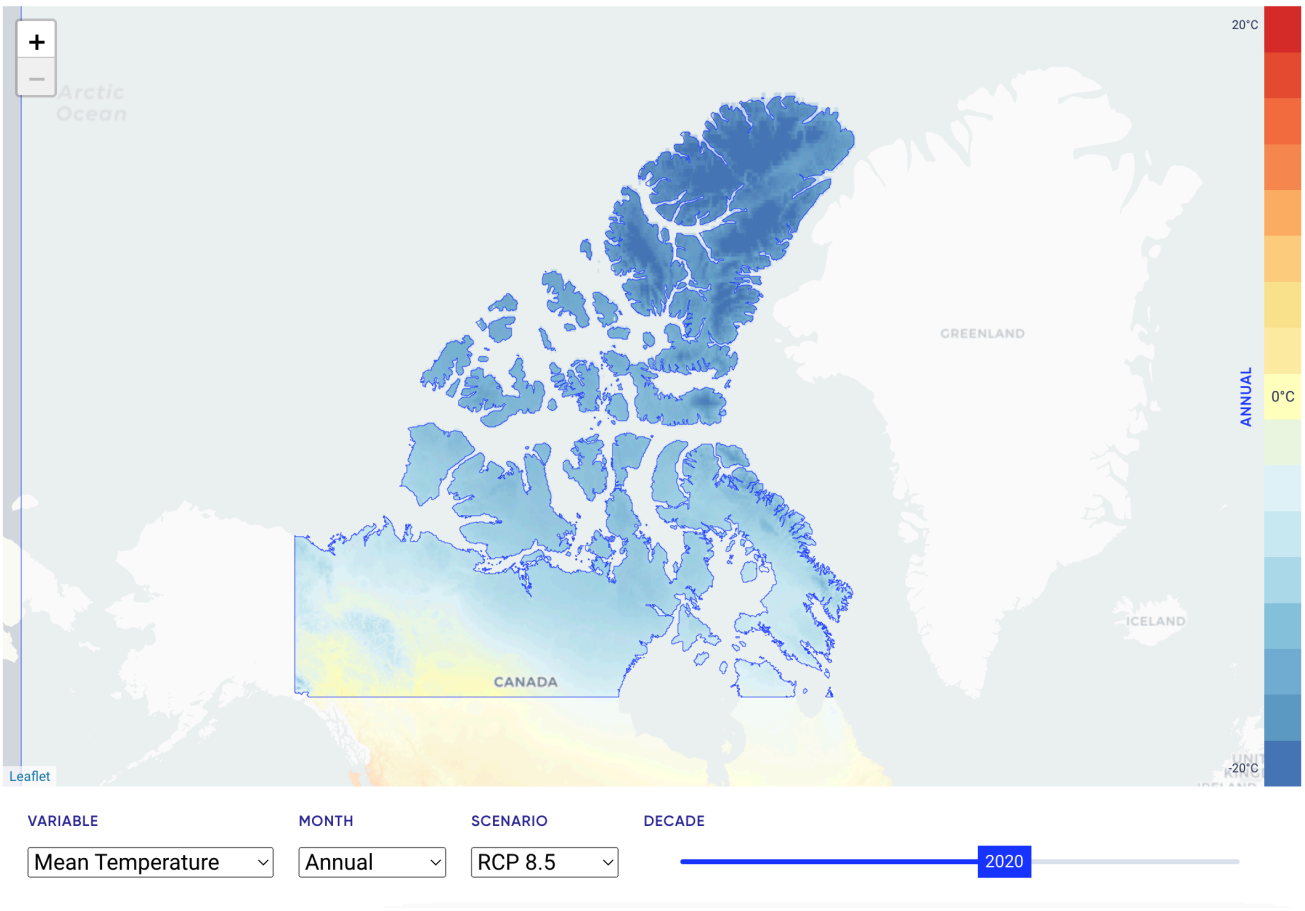


Figure 6.1: Interactive regional map of Northern Canada that draws from climatedata.ca and visualizes various climate variables from 1980 to under three different emissions scenarios: RCP 2.6 (low), RCP 4.5 (medium) and RCP 8.5 (high). Source: climatedata.ca

Canada's status as an Arctic nation elevates the importance of understanding climate change impacts and adaptation. In its report identifying the top climate risks facing Canada, the Council of Canadian Academies identified climate risks to northern communities as being among the top risks for the country (Council of Canadian Academies, 2019). Meanwhile, the development of the Arctic and Northern Policy Framework demonstrates Canada's emphasis on the North as an area of policy focus (Crown Indigenous Relations and Northern Affairs Canada, 2019).

In addition to climate change, the impacts of colonialism and power differentials in Canadian governance and society affect the capacity of Northerners to adapt to change (Council of Canadian Academies, 2019). Indigenous and non-Indigenous Northerners are working within both historical and contemporary treaties, as well as outside of treaties, to overcome this history and to build community resilience. Efforts to support reconciliation guide the decision making of many northern academic institutions and governments (e.g., Wong et al., 2020). In many cases, hunting programs for youth, on-the-land camps, community-centered infrastructure projects and other measures move northern societies towards reconciliation. These measures also improve relationships between community members and strengthen connection to culture, thereby building climate resilience, but such outcomes are rarely direct goals of the activities implemented.

The lived experience of Northerners and the knowledge held over generations as a result of that lived experience, including Indigenous Knowledge and local knowledge, feature prominently in this chapter and are the basis upon which adaptive capacity is built (*see* Box 6.1). While there is regional nuance in the messages conveyed in Box 6.1, the sentiments expressed are common throughout the North. This chapter has attempted to include a diverse range of knowledge, while recognizing that further work in this regard is a necessity, and acknowledging that the scientific framing of this report is not entirely compatible with the holistic and applied intentions expressed below.

Box 6.1: Excerpt from "Inuit, *namiipita?* Climate Change Research and Policy: Beyond Canada's Diversity and Equity Problem"

"Why, in spite of so much research and policy focus on climate change in the Arctic, are we, Inuit, still consultants or fillers in an otherwise Western-driven enterprise to "monitor" climate developments in Inuit Nunangat? The in-situ capacity that Inuit have developed over millennia to observe, analyze, apply and adapt to the changing northern environment is overlooked in the scientific race to research and document environmental transformations taking place in our homelands. We need to turn to a pragmatic approach in the climate change fight—one that starts locally and it presupposes challenging ongoing policy concerns with how to "validate" Inuit knowledge and science. This involves stepping out of the traditional research paradigm and instead directing substantive resources towards the inclusion of Inuit as fully-fledged, distinct researchers and decision-makers.

Inuit are part of the northern ecosystem; thus, a perspective is needed that speaks to the interdisciplinary and holistic nature of *Qaujimajatuqangit* (Inuit traditional knowledge) and way of being of people in this part of

the world. Given that the Inuit are at the centre of the looming environmental crisis, they should also be at the center of the way forward, for everybody's sake.

To be fair, there are attempts to incorporate Indigenous epistemologies and methodologies in research, including university-driven community research projects. By and large though, the lead stays outside of the Arctic, with Inuit merely being consulted on research areas that mainly relate to community development or, at best, being called on to contribute what has been called "traditional ecological knowledge" where research gaps exist.

Inuit participation in climate change and other environmental assessment processes will result in increased applied research capacity, sustainable northern economic development as per Inuit *Qaujimajatuqangit* approaches and an opportunity for our community members to feel re-empowered to reclaim their role as the original stewards and guardians of *Sila* (a spiritual power related to weather), bestowed on us by *Anirnirq* (Great Spirit) and passed on through our *Innait* (elders) and *atarniit* (ancestors).

Arctic warming is certainly a hot topic. For the Inuit in particular, it is a burning issue, as it concerns our homelands, and yet we are left out of the national and global climate change conversation. Gathering evidence to inform policymaking in support of slowing down climate change fits into to a northern research and policy capacity-building paradigm that many of us in the south are used to. The urgency of Arctic change compels an alternative applied and solution-focused paradigm. The capacity is there, but it is a distinct, Inuit-specific capacity; the evidence is there, but it has been gathered and documented in a way that has not historically sat well with the exclusive understanding of science that drives evidence-based policymaking. If we, as a society, are to understand and design pragmatic solutions to climate change, the Inuit need to be at the forefront of the research and decision-making process. Their homelands are most affected, and so are they as a people. Their capacity and evidence does not need to be legitimized, but rather to be seen as a unique asset in approaching climate change in an integrated, applied, holistic manner—one that would mark a different way of investing research resources and of thinking through the complexity of the Arctic ecosystem: land, water, animals, and people. Inuit, *namiipita* (where are you)?"

Source: Pfeifer, 2020, 265–269.

The history of Indigenous-northern settler relations is a critical factor in understanding adaptive capacity in the North, and does not follow a simple timeline. In the Eastern Arctic, contact between Inuit and settlers goes back to the 1500s (Inuit Tapiriit Kanatami, 2004). Even before oppressive policies were introduced, settlers introduced viruses, at times intentionally, and overharvested key species. These actions ravaged many Indigenous populations in this early contact period (Truth and Reconciliation Commission of Canada, 2015a; Inuit Tapiriit Kanatami, 2004). By contrast, contact between Yukon First Nations and settler populations happened much later, after oppressive policies and the Indian Act were entrenched elsewhere in early-Confederation Canada. Throughout the North, Christian religious bodies and the Northwest Mounted Police (later the Royal Canadian Mounted Police) played a prominent role in deploying and implementing policies with the explicit intention of eradicating traditional practices and assimilating Indigenous people into "Western" ways (Coates, 2020).

Northern Indigenous voices were almost entirely absent from any policy development until well into the 1970s (Truth and Reconciliation Commission of Canada, 2015a; 2015b). Instrumental work accomplished during this time period included the James Bay and Northern Quebec Agreement (James Bay Northern Quebec Agreement, 1975), Together Today for Our Children Tomorrow (Yukon Native Brotherhood, 1973), The Dene Declaration (Indian Brotherhood of Northwest Territories, 1975) and the Mackenzie Valley Pipeline Inquiry (Berger, 1976). Since this time, Indigenous populations have been able to begin influencing the policies that had been so detrimental to their People, but this still required Indigenous leaders to largely adopt Western governance approaches. Decades also elapsed before the practice of taking Indigenous people from their homes to attend residential schools was ended in 1996 (Reimer et al., 2010). The first Indigenous Self Governments began to form in the early 1990s (Government of Canada, 1995), but they are not universal among northern Indigenous populations today.

It cannot be understated how deeply past and present-day settler policies have harmed Indigenous Northerners (Truth and Reconciliation Commission of Canada, 2015a; 2015b). This reality is present in every conversation, regardless of the specific subject matter. As such, it is exceedingly difficult to situate how climate change impacts and adaptation actions relate to other issues and priorities. Nonetheless, climate change is clearly a priority. Changes already observed are alarming to both Indigenous and non-Indigenous Northerners, and the projected pace and magnitude of anticipated change pose daunting challenges for all of us. Indigenous Knowledge approaches clearly demonstrate that strictly applying a reductionist "Western science" worldview is unlikely to lead to lasting solutions being adopted by northern communities (e.g., Council of Yukon First Nations and Assembly of First Nations, 2019; Inuit Tapiriit Kanatami, 2019a). Applying Indigenous worldviews allows us to move beyond linear "cause-and-effect" thinking towards more holistic approaches to building community resilience. This is the northern reality.

Within the context described above, this chapter was developed by a northern organization, featuring contributions made primarily by northern authors across Canada. This approach provides those living and working in the North with the opportunity to identify and write about climate change impacts and adaptation as they are being perceived, lived, studied and experienced in northern Canada. Contributing authors brought a range of knowledge types and areas of expertise, and have experience in the diverse environments in which we live, and the issues with which we live.

Like other chapters in this report, the Northern Canada chapter uses a "Key Messages" approach. The development of the key messages and the identification of the contributing authors and case stories featured in the chapter were guided by an advisory committee through an iterative, consensus-based approach. The advisory committee was made up of Northerners from across the Territorial North, Inuit Nunangat and northern Manitoba. Like our contributing authors, this chapter's advisors are diverse in their expertise and lived experience, and they worked together to identify issues relevant across our northern home. The broad, engaged approach used to develop this chapter reflects the existing collaborative spirit that is required in order to understand and respond to the impacts of climate change in Canada's North. The advisory committee met five times—four times virtually, and once in person—to create a long list of topic areas, and then to refine this to a manageable list of draft key messages. This was followed by an effort to recruit authors (ideally who live in the North, and are able to incorporate Indigenous perspectives into their writing). The Coordinating Lead Author and supporting team at Yukon University edited and revised the content, with further contributions from the authors, in order to complete this chapter. The result is a chapter that does

not cover all northern climate change adaptation topics, but rather attempts to capture what our advisors consider, based on their experience and expert opinion, to be high priorities for the North.

The key messages in this chapter range from biophysical impacts—including novel disturbances and accelerated rates of change—to impacts on people and culture, through an exploration of holistic health and wellness, public health and safety, and capacity and innovation. These key messages are intended to illustrate the connection between northern society and cultures, and changes to northern landscapes. The complexity of types and degrees of connection to the land and sea, cascading impacts, and appropriate adaptation responses increase with each key message. Rather than attempt to provide an exhaustive list of impacts and adaptations associated with the key messages presented here, we have used examples and case stories to illustrate the central themes of each key message.

6.1.1 What is "*North*"?

The question of how to apply a definition of "North" to our country is a long-standing one (Graham, 1990); as a result, many definitions exist and for numerous different applications (*see* Figure 6.2). For example, the southern limit of discontinuous permafrost, or the northern limit of the treeline, have been used to delineate "North". Various indices of nordicity (e.g., Hamelin, 1979; Burns et al., 1975) have been developed to inform policy, while territorial or settlement region boundaries have been used to reflect jurisdictional governance (e.g., Inuit Nunangat, the Inuit homeland in Canada; (Inuit Tapiriit Kanatami, 2019b)). In Canada's Changing Climate Report, "the North" is used to refer to the three territories (i.e., the Northwest Territories, Yukon and Nunavut), while "northern Canada" is used to refer to the region north of latitude 60˚ (Bush and Lemmen, 2019).

Figure 6.2: Interactive map illustrating different definitions of "North". Data source: Courtesy of Stephanie Saal, Yukon University.

This chapter takes the approach that "North" is defined by identity; therefore, the key messages presented in this chapter are relevant to those living both inside and outside of more typical definitions of "North." For example, Indigenous Peoples with traditional territories that extend south of territorial borders may identify with key messages presented in this chapter, as may the residents of Inuit Nunangat or remote communities south of 60°N latitude, such as Churchill, Manitoba. A people-oriented definition of "North" allows this chapter to explore the societal impacts of climate change and adaptation responses, and includes those who self-identify as Northerners.

While great diversity exists across Canada's northern region, some commonalities are shared. The North is dotted with small communities, many of which are only accessible by air, sea or winter road, including all communities in Nunavut, Nunavik and Nunatsiavut. While the population of northern Canada is low (Statistics Canada, 2017), populations across the North are growing faster than other parts of Canada. The primary driver in the eastern region of the North is natural growth (where there is a young population with growing families), while migration becomes a larger driver in the western region of the North (Statistics Canada, 2018). Many residents live in urban centres within each region, and the proportion of the population made up of Indigenous Peoples generally increases from west to east across northern Canada (*see* Table 6.1).

Table 6.1: Population of Northern Canadian communities

REGION/ TERRITORY	PROPORTION OF POPULATION SELF-IDENTIFYING AS INDIGENOUS	URBAN CENTRE	PERCENTAGE OF POPULATION WITHIN THE URBAN CENTRE
Yukon	20%	Whitehorse	70%
Northwest Territories	51%	Yellowknife	49.5%
Nunavut	85%	Iqaluit	20%
Nunavik	90%	Kuujjuaq	20%
Nunatsiavut	90%	Nain	44%

Source: Statistics Canada, 2018, 2017.

Communities in northern Canada have a mix of land-based and wage-based economies. Land-based activities are often associated with subsistence activities and cultural practices, while wage-based economies are often associated with resource development and governance. The knowledge economy of Canada's North is also growing, as a result of post-secondary education, innovation and entrepreneurship. Throughout Northern Canada, there is expanding local access to post-secondary education, including the launch of Yukon University in May 2020, the transition of Aurora College towards being a polytechnic university, the strategic partnership between Nunavut Arctic College and Memorial University, and the creation of the Labrador Campus of Memorial University. Investment in infrastructure for post-secondary education in Yukon and innovative programming such as the Dechinta Centre for Research and Learning in Northwest Territories form a part of Canada's financial support for the North (Government of Canada, 2021; 2019a). Inuit Tapiriit Kanatami (ITK), the national representational organization formed to protect and advance the rights and interests of Inuit in Canada, also identified the establishment of a university in Inuit Nunangat as a core component of its National Strategy on Inuit Education (Inuit Tapiriit Kanatami, 2017; 2011).

6.2 Climate change is severely impacting northern landscapes and ecosystems

Climate change is producing severe, and in many cases irreversible, changes to northern landscapes and ecosystems.

Climate change impacts include changing snow and ice conditions, shrubs invading the tundra, shifts in species distribution, increased extreme weather events, and changing disturbance regimes, such as pests and wildfires that are impacting northern ecosystems in unpredictable ways. Northerners are trying to understand the limits of ecosystem resilience and our capacity to adapt to these changes.

6.2.1 Impacts on the cryosphere

Permafrost, glaciers, snow, and lake and sea ice form the literal and figurative foundation for habitat and human society throughout the North. Changes to seasonal and long-term melt or thaw cycles in any part of the cryosphere—frozen elements of our environment, including ice, snow and permafrost—can trigger a cascade of changes in soil or aquatic ecosystem structure, biological productivity and geomorphology that make ecological, economic and social systems vulnerable to long-term and sometimes irreversible changes.

6.2.1.1 Permafrost

Canada's Changing Climate Report (Bush and Lemmen, 2019) documented increases in ground temperature and active layer thickness in all monitoring sites across the North. Temperature trends show that the temperature of cold permafrost (i.e., below -2˚C) in High Arctic locations (which includes most of Canada's northern Arctic Archipelago) has increased more rapidly than the temperature of warm permafrost (i.e., above -2˚C) in locations such as the Central Mackenzie Valley (*see* Table 6.2; Derksen et al., 2019). These differences are due, in part, to the fact that air temperature increases and changing precipitation patterns are reflected more quickly in ground temperature records at higher latitudes, compared to in warm permafrost at lower latitudes, where there is often a mix of liquid and frozen water. A large amount of the energy from increased air temperatures goes into melting solid ice to liquid water without there being a measurable change in the ground temperature (Derksen et al., 2019). There is no established process for measuring (Oldenborger and LeBlanc, 2018) or modelling (Nicolsky and Romanovsky, 2018) liquid water content in warm permafrost; this means that large, unmeasured changes in surface conditions can be taking place even when there is a limited trend in permafrost temperature or active layer thickness. Pan-northern permafrost modelling approaches rely on remotely sensed data and are steadily improving as new mapping and vegetation products become available (Melton et al., 2019), although challenges remain with regard to how these models represent permafrost processes. In addition, many adaptation actions—particularly those relating to community infrastructure—require site-specific characterization of ground-thermal regime, excess ice content, and surficial geology, even in a context of a more detailed synoptic understanding of permafrost changes (Canadian Standards Association Group, 2019). There is a continued need for methodological improvements to characterize permafrost, and data consolidation efforts are being made to maximize use of the limited data.

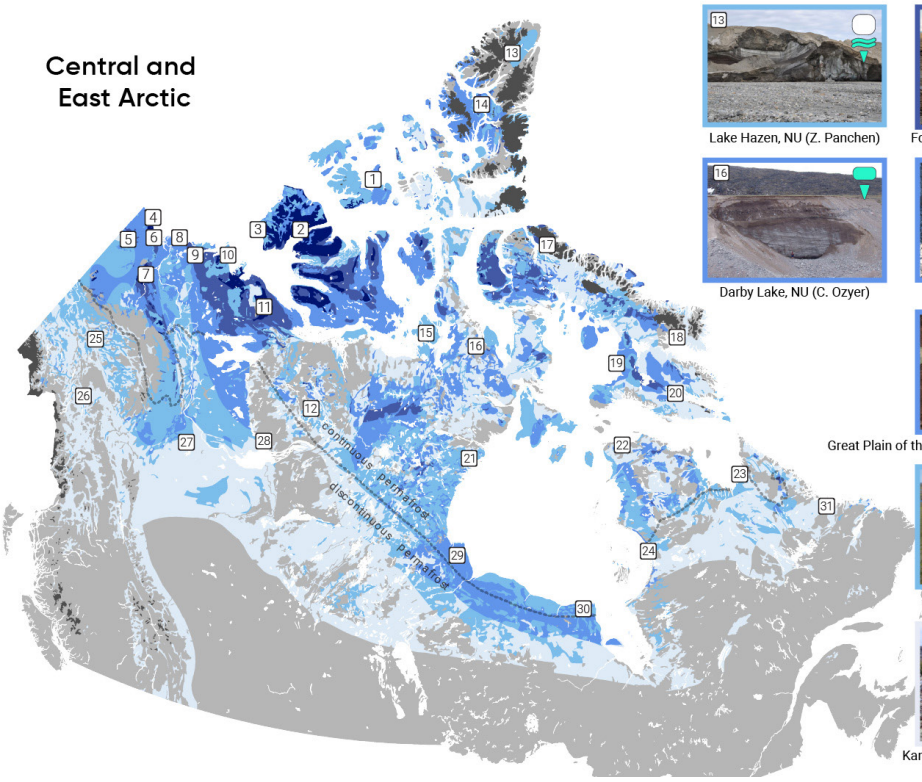
Table 6.2: Changes in permafrost temperature for selected sites across northern Canada

REGION	SITES	INCREASE PER DECADE (℃)	
		ENTIRE RECORD	SINCE 2000
Central Mackenzie Valley	Norman Wells, Wrigley	Up to 0.1	< 0.1 to 0.2
Northern Mackenzie	Norris Ck, KC-07	NA	0.5 to 0.9
Baffin Island	Pond, Arctic Bay, Pangnirtung	NA	0.5 to 0.7
High Arctic	Resolute, Eureka	NA	0.4 to 0.7
High Arctic	Alert	0.5 (15 m), 0.3 to 0.4 (24 m)	1.2 (15 m), 0.7 to 0.9 (24 m)
Northern Quebec (Nunavik)	Akulivik, Salluit, Quaqtaq, Puvirnituq, Tasiujaq, Umiujaq (11–20 m)	0.7 to 1.0	0.5 to 0.9

Source: Table 5.1 from Derksen et al., 2019.

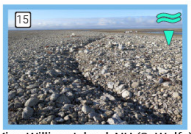
Thawing permafrost in Canada's North, particularly in the discontinuous and sporadic permafrost zones (*see* Figure 6.3), is causing subsidence and uneven landscapes. Spring melt of accumulated snowpack contributes a large portion of the total amount of water within most northern drainage basins. Permafrost, particularly in the continuous permafrost zone, can prevent this water from entering groundwater systems, allowing it to flow overland and to accumulate in lakes, rivers, wetlands and muskeg (Prowse et al., 2006). In permafrost lowlands, soil thawing has led to rapid drainage of lakes or wetlands, with consequences for downstream drainage and wildlife habitat (Carpino et al., 2018; Lantz, 2017; Lantz and Turner, 2015) with potential implications for communities in these regions.

Central and East Arctic



Lake Hazen, NU (Z. Panchen)

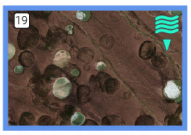
Fosheim Peninsula, NU (A. Rudy)


King William Island, NU (S. Wolfe)

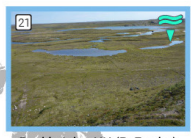
Darby Lake, NU (C. Ozyer)

Pond Inlet, NU (D. Hyatt)

Pangnirtung, NU (D. Hyatt)


Great Plain of the Koukdjuak, NY (©Digitalglobe)

Iqaluit, NU (O. Bellehumeur-Génier)

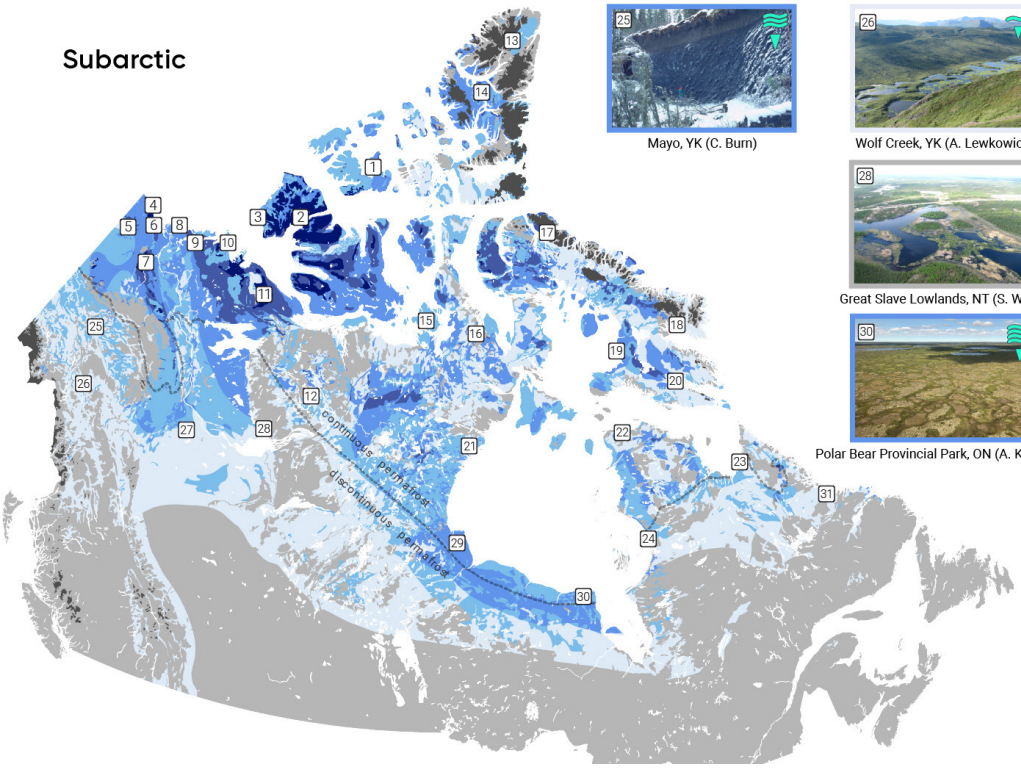

Rankin Inlet, NU (R. Fortier)

Salluit, QC (A.-M. Leblanc)

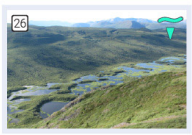
Kangiqsualujjuaq, QC (M. Tremblay)

Umiujaq, QC (F. Calmels)

Subarctic



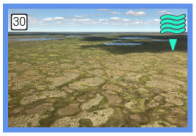
Mayo, YK (C. Burn)


Wolf Creek, YK (A. Lewkowicz)

Scotty Creek, NT (R. Schincariol)

Great Slave Lowlands, NT (S. Wolfe)

Wapusk National Park, MB (W. Sladen)


Polar Bear Provincial Park, ON (A. Kirkwood)

Big Bay, NL (R. Way)

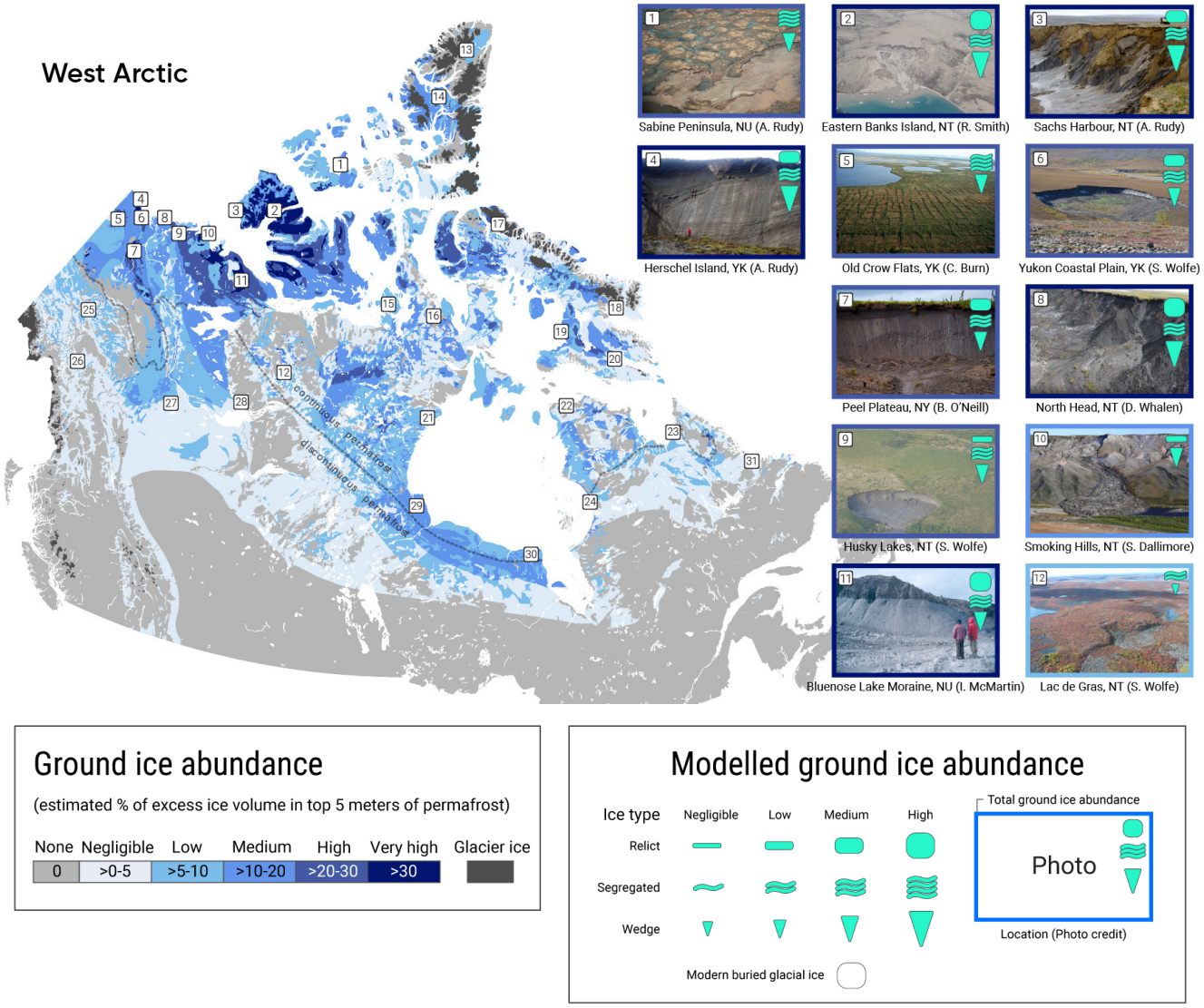


Figure 6.3: This figure highlights the associations between modelled and observed ground ice abundance in the top five meters of permafrost in Northern Canada. It includes photographs from 31 sites across Canada's permafrost regions, illustrating the range of permafrost landscapes and thermokarst–topographic depressions created as a result of thawing ground ice–terrains associated with different ground ice types and abundance. The different ground ice types referred to in the figure include: segregated (i.e., relatively thin and discrete ice lenses or layers that form due to annual downward migration of water), relict (i.e., larger bodies or layers of ice preserved in permafrost by persistent cold-climate conditions) and wedge (i.e., ice that develops when low winter temperatures cause the ground to contract under stress and crack). Source: Adapted from Wolfe et al., 2021.

Permafrost is known to contain contaminants such as heavy metals. As permafrost thaws, these contaminants are being released into groundwater, lakes and rivers, and then can be ingested or absorbed by animals (Miner et al., 2021), impacting the health of these animals and the people who harvest them (*see* Section 6.2.2; Furgal and Prowse, 2008; Warren et al., 2005; Wrona et al., 2005). Access to clean water is

also affected by permafrost thaw—partly by increased contaminants, and also by increased sedimentation as permafrost-rich riverbanks erode more quickly (Anisimov, 2007).

The ability to predict rates of thaw is limited due to the lack of available data and an incomplete understanding of the underlying processes (Holloway and Lewkowicz, 2019). Some maps provide a broad overview of expected or actual permafrost conditions (O'Neill et al., 2019; Bonnaventure et al., 2012; Heginbottom et al., 1995), but are of limited utility for decision making at a local scale. In contrast, site-specific studies (e.g., Calmels et al., 2015) and hazard maps (*see* Figure 6.4) are useful at a local level, but are not available for all northern communities (Calmels et al., 2016; Allard and L'Hérault, 2010). Research networks, such as Arctic Development and Adaptation to Permafrost in Transition (Arctic Development and Adaptation to Permafrost in Transition, n.d.) and PermafrostNet (Brown et al., 2020), are working with local experts to add to the knowledge base and to develop standard data collection protocols for both local and pan-northern scales (*see* Section 6.5.4).

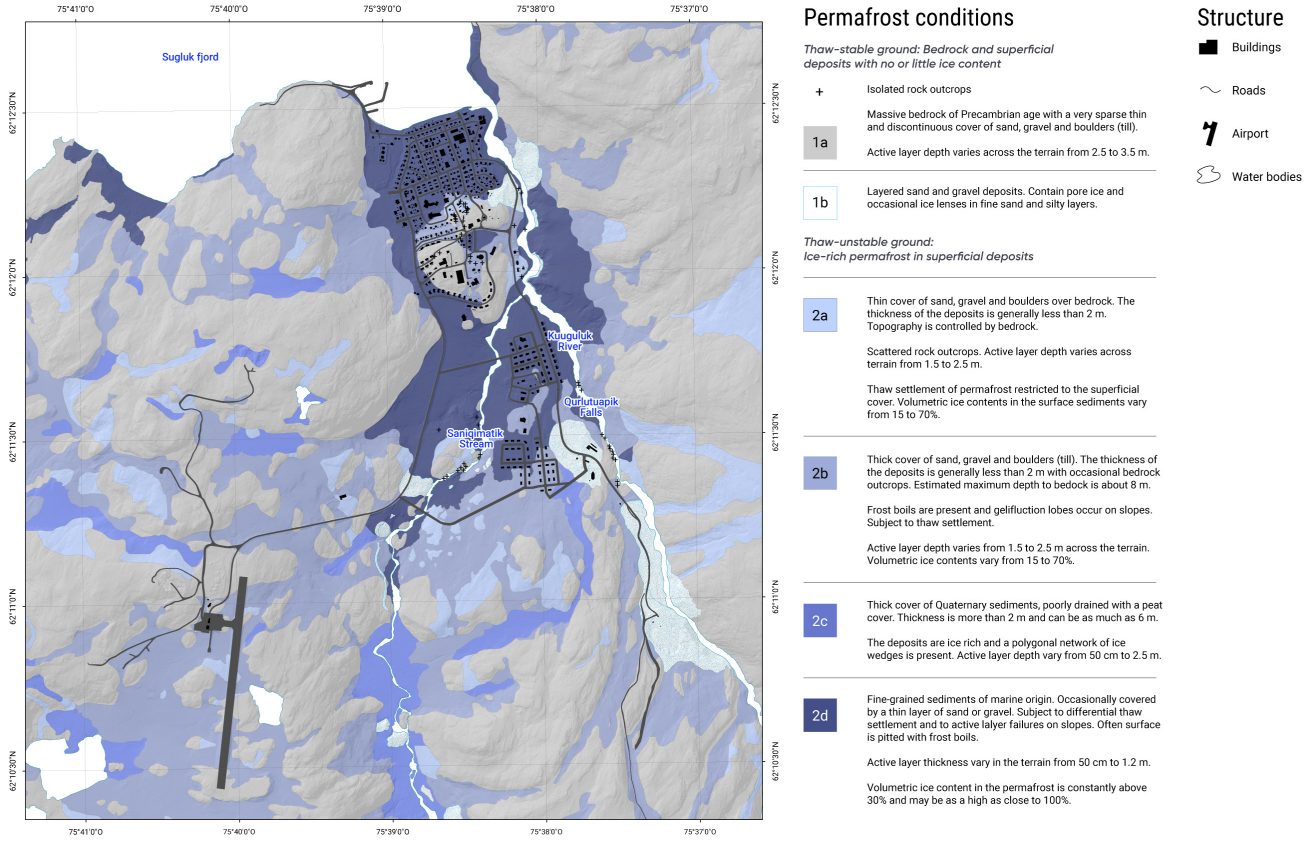


Figure 6.4: Landscape geohazard map for Salluit, Nunavik, summarizing permafrost thaw hazards at the local level. This map was used to inform planning and development in the community and at its airport. Source: Adapted from Allard et al., 2020.

6.2.1.2 Glaciers

Canada's glaciers in Nunavut, Northwest Territories, Yukon, British Columbia and Alberta (*see* Figure 6.3) are rapidly losing mass due to climate change, and this trend is projected to continue (Bush and Lemmen, 2019). Canada's Arctic glaciers will likely persist for several centuries (Huss and Hock, 2018; Bliss et al., 2014; Radić and Hock, 2014); however, Canada's western sub-Arctic glaciers are expected to be gone by the end of this century (Clarke et al., 2015).

Glaciers are important to culture and feature in oral traditions as sentient and responsive elements of the socio-biophysical system (Cruikshank, 2007). The impacts of melting glaciers due to climate change are being felt throughout river basins in northern Canada. Changing streamflow affects downstream ecosystems as well as Northerners who depend on lake and river systems for subsistence. Glaciers in the Canadian Arctic are poised to become the leading contributor to sea-level rise among all glacierized regions (outside of the Greenland and Antarctic ice sheets) by the end of the century (Hock et al., 2019; Radić and Hock, 2014).

Calving and the retreat of high Arctic glaciers have resulted in some fjords being free of floating glacier tongues for the first time in over 3,000 years (Sharp et al., 2014). Melting glaciers bring uncertainty about the future availability of fresh water, and the impacts on downstream hydroelectric power generation in the Yukon, and on flooding frequency and magnitude throughout glacierized basins in the North (Derksen et al., 2019).

6.2.1.3 Sea ice

Decreases in sea ice thickness and cover (Derksen et al., 2019; Meredith et al., 2019; Meier et al., 2014) have impacted Arctic and marine ecosystems (Arctic Monitoring and Assessment Programme, 2017). The most pronounced physical changes include a 40% decrease in fall sea ice extent and concentration in the last 20 years (Niemi et al., 2019), and a loss of sea ice volume coupled with a dramatic decrease in multi-year sea ice (Perovich et al., 2019; Kwok, 2018). Spring sea ice extent and concentration remain relatively stable, but this ice is thin and young, which is very different from what was present in previous decades (Perovich et al., 2019).

6.2.2 Impacts on marine ecosystems

In natural systems, the impacts of sea ice and glacier melt affect the environmental conditions for many species (Bhatia et al., 2021; Niemi et al., 2019). In addition to the direct impacts of the loss of sea ice as a platform for habitats, climate change is having indirect impacts on environmental stressors such as coastal erosion and slumping (the downward movement of rock debris) (Couture et al., 2018), ocean acidity (Niemi et al., 2019; Qi et al., 2017) and productivity (Bhatia et al., 2021). Understanding of ecosystem responses to these stressors has rapidly developed—aided significantly by collaboration among Indigenous and non-Indigenous knowledge holders (Williams et al., 2020). There is increasing evidence to indicate a mix of positive, negative impacts, as well as non-impacts on species (*see* Figure 6.5). In addition, there is significant sub-regional complexity in marine ecosystem response highlighting the connectivity to physical and biologic systems that are still not fully understood (Niemi et al., 2019).

Overall, the increased ice-free season has supported more primary productivity as light is able to penetrate the water column for a longer period of time (Renaut et al. 2018). However, there is evidence that lack of nutrients limits primary productivity at some locations (Blais et al, 2017, Bergeron and Tremblay, 2014). Some species are resilient to shifts in timing of phytoplankton blooms, and have an ability to shift to other food sources or to spend more time feeding in ocean waters. For example, Arctic char, Greenland halibut, seals and beluga are able to shift to consuming prey such as capelin that are, in turn, consuming phytoplankton rather than sea ice algae (Yurkowski et al. 2018). The impact of these changes in diet continues to be an active area of study. Switching to other prey that may not offer the same level of nutrients may compromise health, while expending additional energy searching for new prey or diving to deeper depths may be problematic (Choy et al., 2019, 2020, Loseto et al., 2018).

Indigenous Knowledge and community-based observations have contributed to an improved intra-annual and interannual understanding of Arctic marine systems, particularly in near-shore coastal environments. For example, collaborative studies have identified hotspots of productivity, have helped to demonstrate the importance of transition zones between water bodies for key species such as Arctic cod, and have led to further research into species such as Pacific salmon entering the Beaufort Sea, and orcas entering many Arctic waters (Niemi et al., 2019). Still, there are many uncertainties regarding the impacts of climate change on commercial and subsistence harvests (*see* Figure 6.5), requiring ongoing research to address knowledge gaps.

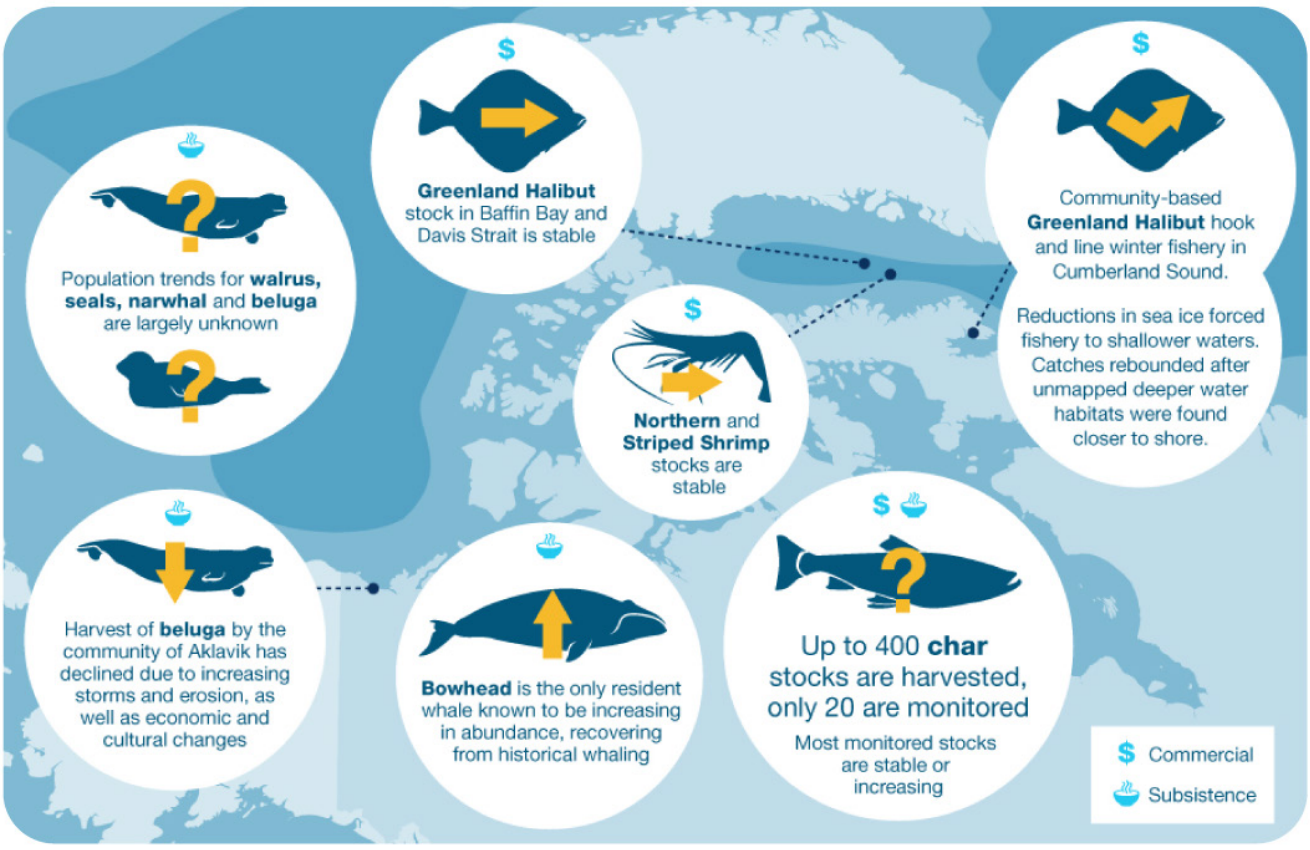


Figure 6.5: Climate change impacts and trends in several key species that are harvested for subsistence or commercial purposes in the North. Source: Department of Fisheries and Oceans Canada, 2019a.

The creation of Tuvaijuittuq Marine Protected Area along the northern coast of Ellesmere Island is expected to help provide habitat protection in the summer for numerous ice-dependent species, including polar bear, walrus and seals (Newton et al., 2021; Department of Fisheries and Oceans Canada, 2019b). The oldest, thickest ice remaining in the Arctic is found in this region, and this is expected to be the last ice area as climate change impacts continue. This marine protected area also represents a significant achievement in terms of embracing collaborative management, with co-governance shared among Indigenous, Territorial and Federal authorities (Department of Fisheries and Oceans Canada, 2019b).

6.2.3 Impacts on vegetation

In addition to physical changes in landscapes due to permafrost thaw, warmer or drier conditions are are leading to an increase in disturbance agents, including forest pests and wildfire. Along the boreal forest-tundra ecotone (the transition area between two plant communities), forest insects are now able to survive warmer winters, resulting in a range of impacts. For example, in 2015, the spruce budworm (*Choristoneura fumiferana*) caused unprecedented spruce defoliation in the Mackenzie Delta (Olesinski and Brett, 2015). Canada's northwest boreal forest has seen increased fire frequency and severity (Meredith et al., 2019, Natural Resources Canada 2017), with wildfires increasing due to climate change and other stressors (*see* the Sector Impacts and Adaptation chapter of the National Issues Report; Coogan et al., 2019). The area burned and the number of large fires in northern Canada have increased over the last half-century (Hanes et al., 2018). Wildfires are projected to increase in frequency and severity, and to become more widespread across Canada, including in the North (Coogan et al., 2020; Coogan et al., 2019; Hu et al., 2015). How these changes impact local and regional vegetation is a function of ecosystem resistance, resilience and vulnerability (*see* Box 6.2).

Box 6.2: Ecosystem resistance, resilience and vulnerability

Ecological systems are dynamic and change over time, often in response to disturbances. For example, a wetland may become flooded temporarily due to heavy spring rainfall, or it may become drier when thawing permafrost allows increased drainage through formerly frozen soil. Alternatively, if soils remain dry for a long period after a fire, a wetland could become a completely different system. Such disturbances happen at large and small scales in virtually all ecosystems. The responses to these changes will depend on both the ability of the ecosystem to remain the same when disturbed (resistance) and the ability of the ecosystem to respond to change, absorb damage and recover quickly (resilience). Northern ecosystems are most resilient to disturbances and environmental conditions within the historic range of variability and previous adaptation (*see* Figure 6.6a; Johnstone et al., 2016; Seidl et al., 2016; Keane et al., 2009). Resilient ecosystems may respond quickly or slowly; the key element is the ability of the system to recover its essential structure or function following a disturbance or change (Holling, 1973). If collapse is triggered by disturbance, there may be a chaotic period followed by eventual re-establishment of the previous state, or a new pathway may emerge in response to the many "chance" circumstances during the chaotic period (*see* Figure 6.6b; Holling, 2011).

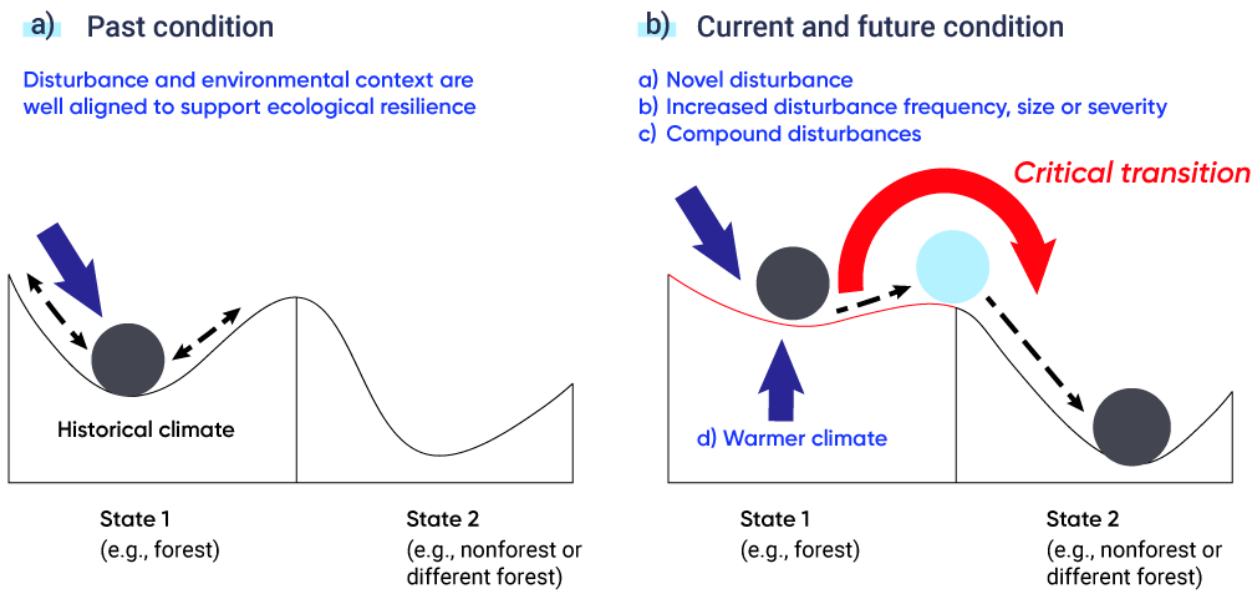


Figure 6.6: Conceptual representation of an ecosystem (portrayed by a black ball) within a theoretical landscape of alternative ecosystem states (portrayed by valleys separated by peaks). a) The ecosystem is resilient to disturbances lying within the historical range of variability and previous adaptation, indicated by disturbances that may move the system, but not cause it to shift to another state. b) The ecosystem is likely to shift to a different state in response to hypothesized mechanisms that move the ecosystem beyond its historical range of variability and previous adaptation, and trigger a shift to a different ecosystem state. Source: Adapted from Johnstone et al., 2016.

Climate change is directly impacting vegetation, with substantial areas of tundra and northern boreal forest in northern and eastern Canada showing increased vegetation productivity (*see* Figure 6.7; Keenan and Riley, 2018; Sulla-Menashe et al., 2018; Ju and Masek, 2016). Local knowledge and Indigenous Knowledge, remote sensing and scientific monitoring indicate that much of the greening of the tundra is due to expansion of woody shrubs (shrubification), such as alder and tall willows, in areas that formerly supported vegetation of much lower stature (Dän Keyi Renewable Resources Council, 2019; Myers-Smith et al., 2019; 2011; Lantz et al., 2013;). Shrubification is causing a shift from tundra to shrubland that will not be reversed without a return to previous climate conditions (Mekonnen et al., 2021); this is one of the largest manifestations of change observed widely across northern Canada (Tremblay et al., 2012; Fraser et al., 2011, Hill and Henry, 2011; Myers-Smith et al., 2011; Thorpe et al., 2002).

Disturbances such as wildfire and insect infestations are influenced by many factors, which interact with climate to cause changes to northern ecosystems (Johnstone et al., 2016). Many ecosystems may be initially resistant to change, given that feedbacks associated with long-lived vegetation help to maintain environmental conditions and ecological functions that support ecological stability even when the climate is changing (Chapin et al., 2004). However, when vegetation is killed or reduced through a disturbance, these feedbacks are disrupted and rapid change can occur (*see* Figure 6.6). For example, stand-replacing wildfires

initiate new phases of forest regeneration where seedlings may be much more sensitive to climate conditions than in an established stand where canopy trees substantially alter the local microclimate (Baltzer et al., 2021; Davis et al., 2019; Johnstone et al., 2010). Climate change will also directly affect the type and severity of disturbances that occur, since factors such as fire behaviour, insect pest biology and permafrost thaw are all sensitive to changes in seasonal weather conditions (Turetsky et al., 2017).

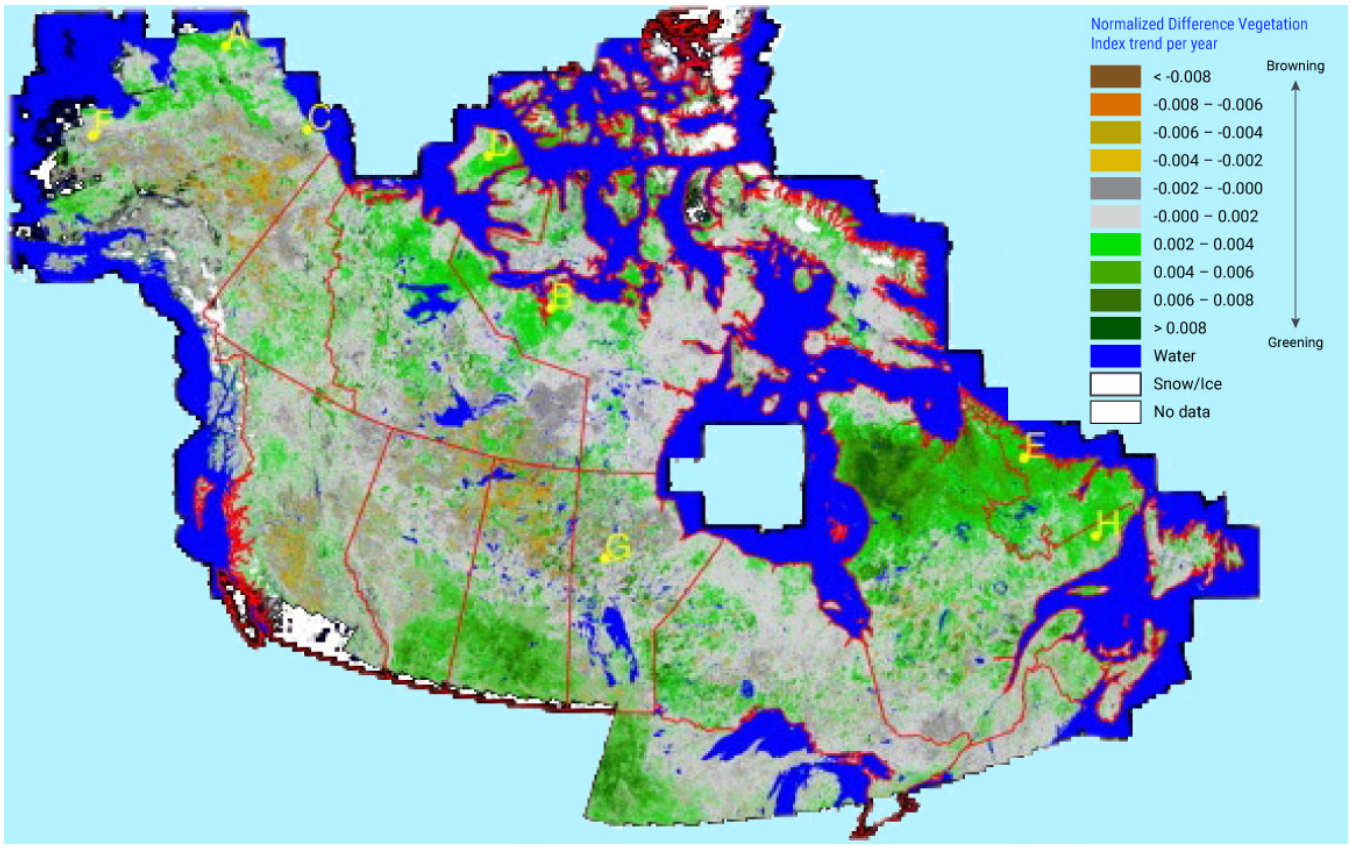


Figure 6.7: Landsat-based maps showing greenness trends through the use of the Normalized Difference Vegetation Index (NDVI), which estimates the density of greenery in an area using the difference between visible and near-infrared reflectance of vegetation. Where there were not enough valid observations to derive greenness trends, all thematic layers were set to "no data." Letters A to H represent ground validation sites. Source: Adapted from Ju and Masek, 2016.

In contrast to the tundra, much of the boreal forest shows little change in vegetation greenness with regionalized areas of declining productivity (*see* Figure 6.7, Ju and Masek, 2016; Goetz et al., 2005). In some cases, "browning" trends in the boreal forest reflect the impacts of disturbances such as logging and wildfires (Bonney et al., 2018). However, in the northern parts of the boreal forest, there is evidence from tree rings that warming may cause increased drought stress and reduced tree growth (Walker et al., 2015).

6.2.4 Impacts on terrestrial animals

The frequency of extreme weather events, including anomalous warming events during the winter and during rain-on-snow events, has increased across the Arctic (Cohen et al., 2015). Rain-on-snow events cause an impenetrable layer of ice over the ground, which can lead to starvation and population crashes for ungulates (hooved animals) across the Arctic, such as the death of 20,000 muskoxen on Banks Island in 2003 (Rennert et al., 2009).

Currently, many of Canada's caribou populations are in decline due to habitat disturbance. Increasingly, climate change is acting to magnify the disruption of habitat, particularly for woodland caribou (Stewart et al., 2020; Mallory and Boyce, 2017; Gunn et al., 2009). Migratory herds of barren-ground caribou vary substantially in their responses to climate change and habitat disturbance, with most showing negative responses due to difficulty foraging during winter following tundra fire or rain-on-snow events (Schmelzer et al., 2020; Lewis et al., 2019) and some showing positive effects due to increased reproduction success during warmer spring, and improved body condition following warmer winters (Gagnon et al., 2020; Mallory and Boyce, 2017; Wheeler et al., 2017; Gunn et al., 2009). Impacts on caribou are not always gradual, with catastrophic die-off events being associated with extreme precipitation (e.g., rain-on-snow) (Miller and Gunn, 2003). Such observed impacts likely represent the beginning of substantial reorganization of ecological communities in the North in response to climate change (Reid et al., 2013; Post et al., 2009). Traditional caribou harvest practices are severely impacted when caribou migratory routes shift away from historical locations (Douglas et al. 2014). While management practices have evolved to better include Indigenous perspectives, decisions regarding caribou harvest and habitat remain an important, and often contentious, policy issue (Vuntut Gwitchin Government, 2020; The Committee on the Status of Endangered Wildlife in Canada, 2017; Cuerrier and the Elders of Kangiqsualujjuaq, 2012).

In some habitats in the central Canadian Arctic, vegetation productivity has increased (*see* Figure 6.7), although this is not occurring in other habitat types (Rickbeil et al., 2018). Although caribou may benefit in some years from increased vegetation productivity (Mallory et al., 2018), earlier greening of vegetation associated with earlier starts to spring weather, may decrease the quality of forage available to animals during key reproductive periods (Barboza et al., 2018; Post and Stenseth, 1999).

Climate change has created the conditions for new species to inhabit northern Canada, primarily by expanding their northern ranges (Chen et al., 2011). Some newcomer species are responding to new habitat resulting from shrubification of the tundra (Myers-Smith et al., 2011). These include the American Robin (*Turdus migratorius*) and Wilson's Warbler (*Cardellina pusilla*), which have expanded their breeding range northward by 100 to 350 km in northern Labrador (Whitaker, 2017), as well as the North American beaver (*Castor canadensis*), which has been colonizing the treeless tundra on the Beaufort Coastal Plain in parts of the Yukon and Alaska (Tape et al., 2018; Jung et al., 2016).

In Nunavik, Indigenous Knowledge indicates that beavers have been moving further north, blocking rivers that Arctic char depend on for reproduction (Inuit Circumpolar Council, 2018). Because there is limited Indigenous Knowledge about beaver harvesting in the area, local trappers and hunters are being forced to learn new techniques to manage beaver, and are unsure of the impact that beavers are having on Arctic char (Shah et al., 2018). Workshops, surveys and interviews indicate widespread Indigenous observation of new wildlife,

birds, insects and fish entering regions, as well as an in-depth understanding of the health of existing species (Knotsch and Lamouche, 2010; Nickels et al., 2005; Krupnik and Jolly, 2002).

New assemblages of species result in novel interactions. It is expected that southern migrants will displace some northern species, particularly those experiencing a range retraction due to diminishing cold habitat (Marcot et al., 2015). Some new species will have more impact than others—for example, beavers are a keystone species and significantly reshape landscape hydrology by building dams. The resulting ponds can increase the thawing of permafrost, thus enhancing the impacts of climatic warming (Tape et al., 2018).

6.2.5 Cascading impacts

New forms of disturbance can induce positive feedbacks that amplify warming and other climate-induced impacts. For example, following a wildfire, ground-cover changes locally amplify warming temperatures, contributing to shrubification of the tundra and permafrost thaw, while also releasing carbon that contributes to additional warming (Jones et al., 2015; Lantz et al., 2013). Negative feedbacks also occur. For example, moisture availability is higher in warm spring conditions, but can produce precipitation in the form of snow, thus increasing albedo and slowing melt (Fletcher et al., 2012; Qu and Hall, 2007). Furthermore, a cascade of disturbances can occur whereby one novel disturbance creates the conditions for another novel disturbance. For instance, increased moisture and humidity across the Northwest Territories in 2017–2018 may have increased pathogens in forests of the Northwest Territories (Olesinki and Brett, 2018).

The impacts of both new and existing disturbances may compromise ecosystem resilience (Johnstone et al., 2016). For instance, wildfires that burn under typical conditions are unlikely to severely disrupt the natural cycles of forest succession, as most boreal tree species have adapted to ensure regeneration after fire. However, increased fire activity may cause stands to burn at young ages before trees are old enough to generate seeds. Such events, especially when they occur in combination with unusually dry or warm years, can trigger regeneration failures and cause shifts to non-forested states (Whitman et al., 2019, 2018). While tundra systems may be less vulnerable to disturbance-induced changes, large fires do occur in tundra environments (Mack et al., 2011), and increased fire activity may result if temperatures cross climate thresholds that have regulated fire activity in the past (Young et al., 2017).

6.3 Health impacts are intensifying and amplifying inequities in the North

Climate change is negatively impacting the health of Northerners, amplifying existing inequities and access to healthcare.

Not all climate change impacts on health are direct. Physical health impacts include disrupted access to country foods, increased exposure to contaminants and wildfire smoke, and increased travel hazards. Mental health challenges arise from changing land access, disruptions to cultural activities and knowledge sharing opportunities, shifting place-based identities, and loss of important species, plants, or ecosystems. Locally appropriate, culturally relevant resources and programming, co-created by local communities in partnership with other organizations, are critical to support climate-sensitive physical and mental health outcomes. Such resources and programs must include connection to place and promote increased time on the land to enhance wellness and decrease the strain on limited healthcare resources.

6.3.1 Introduction

In northern Canada, people often live in close proximity to their environment, relying on the land to support their livelihoods, well-being and, particularly in Indigenous contexts, their culture and identity (Richmond and Ross, 2009; Kirmayer et al., 2008). This means that even subtle alterations in climate and the environment can disrupt peoples' lives and connection to place, ultimately affecting their mental and emotional health. Rising temperatures, decreased sea ice extent and stability, disruptions to food and water resources, and changes to wildlife and plants are impacting livelihoods, cultural practices and knowledge sharing.

Northerners are also concerned about physical health impacts related to the release of naturally occurring contaminants from the melting cryosphere and from increased exposure to wildfire smoke. While the body of literature related to the actual risks for northern Canadians is limited, the perception of risk is high.

6.3.2 Mental health

Mental health is a major public health and health system priority in northern Canada, particularly among Indigenous Peoples, who face significant health disparities and have limited access to mental health services (*see* the Climate Change and Indigenous Peoples' Health in Canada chapter of the Health of Canadians in a Changing Climate Report). The sources of mental health challenges are complex, stemming from intergenerational trauma triggered by forced relocation, land dispossession and residential schools (Inuit Tapiriit Kanatami, 2016; Cunsolo Willox et al., 2014; Kirmayer et al., 2008), as well as inequities in accessing culturally safe care.

Climate change has emerged as an additional direct and indirect stressor on mental health (Clayton et al. 2017; Cunsolo Willox et al., 2013a, b, 2012). For example, increasingly unpredictable weather conditions,

combined with sea ice loss and other climate change impacts across northern Canada and Inuit Nunangat, are compounding and exacerbating existing mental health challenges for Indigenous Northerners. This is creating new mental health stressors by diminishing the ability of Indigenous Northerners to safely engage in land-based activities and maintain connections to their ancestral lands and cultures (Durkalec et al., 2015; Harper et al., 2015; Healey, 2015; Petrasek MacDonald et al., 2015; Cunsolo Willox et al., 2013a, b; Petrasek MacDonald et al., 2013). These disruptions to beloved lands, waters, plants and animals are having diverse emotional and mental impacts, as several Inuit-led and community-driven studies have identified (*see* Case Story 6.1).

Case Story 6.1: *Attutauniujuk Nunami/Lament for the Land* Documentary

Attutauniujuk Nunami/Lament for the Land originated out of a community-based, community-led initiative to examine connections between climate change and Inuit mental health in Nunatsiavut (the Inuit Mental Health and Adaptation to Climate Change project). It represents a joint partnership of the five Inuit communities of Nunatsiavut, with coordination in each of the five regions provided by a local research coordinator. A total of 120 interviews conducted with community members and health professionals resulted in a film that highlights the voices of Inuit in Nunatsiavut as they describe the impacts of climate on mental health, and associated adaptations (Cunsolo Willox et al., 2013c). *Attutauniujuk Nunami/Lament for the Land* highlights the ways in which people and place are intimately connected, and the grief and sadness, as well as the hope and strength that emerge in times of change.

Learn more by seeing *Lament for the Land*, 2022.

Decreased time on the land due to changing environmental and weather conditions has been linked to strong emotional reactions such as: anger, fear and sadness; interpersonal distress; possible increased drug and alcohol use; triggering and magnification of previous traumas; potential for increased risk of suicide; challenges to people's identities rooted in place; and a greater burden on healthcare staff for mental health needs during times of limited mobility and reduced land access (Middleton et al. 2020a, b; Bunce et al., 2016; Durkalec et al., 2015; Harper et al., 2015; Ostapchuk et al., 2015; Wolf et al., 2015; Cunsolo Willox et al., 2013a, b; Petrasek MacDonald et al., 2013; Cunsolo Willox et al., 2012). For example, health workers in Rigolet, Nunatsiavut, report that the stress of not being able to be on the land carries over to the familial environment, resonates through the community, and anecdotally results in increased substance use (Cunsolo Willox et al., 2013b).

Reduced opportunities for sharing skills and knowledge, and for subsistence harvesting and subsequent food sharing, are also impacting the social bonds and cohesion within communities (Bunce et al., 2016; Cunsolo Willox et al., 2013b; Pufall et al., 2011). Current and anticipated environmental loss due to climate change is eliciting strong emotional responses. These include: stress, distress and despair (Ellis and Albrecht, 2017; Harper et al., 2015; Ostapchuk et al., 2015; Cunsolo Willox et al. 2013a, b; Cunsolo Willox et al., 2012); solastalgia (emotional and existential stress connected to changing or disrupted environments and

connections to place) (Albrecht, 2012); and ecological anxiety and ecological grief (i.e., grief and anxiety in response to physical ecological loss, disruptions to knowledge and cultural systems, and shifting place-based identities (Cunsolo et al., 2020; Cunsolo and Ellis, 2018).

Climate-sensitive mental health impacts require specific and multi-faceted responses to match the diverse psychosocial impacts that are occurring. Such responses may also have co-benefits for other mental health stressors. When support is provided to enhance mental healthcare resources for northern communities, this helps to ensure that residents have access to appropriate therapy and counselling, while education and training for healthcare staff and patients would raise awareness of the mental health impacts resulting from climate change, such as ecological grief (Cunsolo et al. 2020; Middleton et al. 2020b; Cunsolo and Ellis, 2018; Clayton et al., 2017). To address the broader socio-environmental determinants of mental health, many mental health adaptations need to take place outside of the formal healthcare setting. This may include, but is not limited to, community programming that facilitates social cohesion and connection to culture, and provides individuals and communities with a sense of self-efficacy, and opportunities for meaningful action to reclaim their stories in a changing climate (Clayton et al., 2017). Where possible, programming can aim to maintain and enhance peoples' connection to place (Clayton et al., 2017), while also having mental health resources that are not dependent on land or weather conditions, such as climate-resilient culture camps, and thus can be accessed outside of challenges imposed by climate change (Cunsolo Willox et al., 2013b).

6.3.3 Food insecurity

Food insecurity risks for Arctic peoples are increasing as a result of climate change impacts, which are compounded by the impacts of development and economic structures (Meredith et al., 2019). Canada's highest rates of food insecurity are all in the North, with recent studies identifying a regional prevalence of household food insecurity that ranges from 16.9% in the Yukon (Tarasuk and Mitchell, 2020) to 59.5% in Nunatsiavut (Furgal et al., 2017). All dimensions of food insecurity—availability, access, quality, use and stability—are impacted by climate change and its associated environmental changes, which affects virtually all aspects of wellness, including physical and mental health (*see* Food Safety and Security chapter of the Health of Canadians in a Changing Climate Report).

Northern food systems are both complex and distinct. Indigenous and non-Indigenous Northerners continue to rely on what can be generally described as a dual food system made up of both market foods (imported foods purchased at stores through the market economy) and country or wild foods (foods hunted, harvested or gathered from the land, sometimes referred to as traditional foods) (Hansen et al., 2018). Market and country foods have distinct and sometimes interacting mechanisms of food availability, processing, distribution, access and disposal. Adverse and anomalous weather events—such as increasing precipitation, severe winds and prolonged fog—affect the availability and accessibility of all foods. Higher numbers of foggy and windy days negatively affect the transportation of market foods into communities, both by air and marine shipping. These climate-related delays have reduced the availability and quality of market foods in communities, while also contributing to increased costs (Human Rights Watch, 2020; Cunsolo Willox et al., 2012). The same conditions make travel on the land, water and ice more difficult for hunters and harvesters, restricting the accessibility of country foods, the amount of time spent on the land, and the transmission of cultural

knowledge. Activities on the land allow people to provide for their families and are essential for Indigenous food security and sovereignty. They are also central to the health and well-being of Arctic residents.

Addressing the negative impacts of climate change on food security is facilitated by policies and programming that encourage and facilitate the practice of land-based activities, as well as participation in market economies (Wilson et al., 2020). Community freezer programs provide access to equipment, training and knowledge that support hunter access to, and safety on, the land, water and ice, while enabling the distribution of country foods within communities (*see* Case Story 6.2). In both Nain and Hopedale, the Department of Health and Social Development of the Nunatsiavut Government operate *Nigivik* ("A place where we eat" in Inuttitut, a dialect of Inuktitut) programs. Often offered in partnership with community freezer and youth programs, *Nigivik* programs offer accessible and flexible cooking spaces and activities that focus on teaching cooking and other food skills to community members of all ages. To address the changing availability of country foods, *Nigivik* emphasizes the importance of both country foods and market foods for health, while teaching skills such as traditional methods of food preservation and contemporary canning, both of which can increase year-round accessibility of country foods (The OKâlaKatiget Society, 2017).

Case Story 6.2: Community freezer programs in Nunatsiavut

Designed to support access to country food, community freezer programs act as a central community repository of country foods that are redistributed throughout communities in Nunatsiavut (Organ et al., 2014). Such programs increase access to country foods and reduce the risk of travel in a changing climate. They also have important co-benefits, including increasing mental wellness and the transmission of cultural knowledge.

Community freezer programs (*see* Figure 6.8) are tailored to meet the needs of each Nunatsiavut community, and are a contemporary formalization of the Inuit value of sharing. In addition to increasing access to a diversity of country foods, many community freezer programs include initiatives to address other challenges to country food access and food security. In Nain, the community freezer program includes a fuel and hunting resources program, where harvesters are provided with essential supplies in return for sharing a portion of their catch with the freezer. Harvesters borrow fishing rods, GPS and InReach units, camping equipment and other essential safety gear that they may not otherwise be able to access. This addresses barriers to harvesting created by increasingly expensive costs of equipment, as well as the risks to individual safety posed by the increasing unpredictability of travel on the land and ice. In several communities, community freezer programs also operate youth and mentorship initiatives, where experienced hunters are hired to take youth out on harvesting trips. These programs train youth in essential harvesting and food security skills and knowledge, while also providing harvested foods to the freezer programs or directly to Elders in the community.

Figure 6.8: Infographic of quick facts about the Community Freezer Program in Hopedale, Nunatsiavut.
Source: Adapted from Food First NL, n.d.

In most communities, community freezers and programs like *Nigivik* contribute to a suite of initiatives that together support adapting to climate change. Although not all were developed as climate change adaptation programs, these initiatives offer co-benefits that include building individual and community climate resilience. Community and regional-scale programs are also complemented by a number of overarching policy initiatives, including the National Inuit Climate Change Strategy (Inuit Tapiriit Kanatami, 2019a) and the Nunatsiavut Food Security Strategy/Imappivut Marine Plan, currently being developed by the Nunatsiavut Government. In the development of these and other strategies, considerations of health and food security are embedded to ensure that associated policies and programs are intersectoral and grounded in Inuit values and ways of life to promote wellness and resilience. Importantly, such strategies recognize and empower inherent capacity (*see* Section 6.6) and draw on both Inuit knowledge and scientific evidence to put people at the core of resilience.

6.3.4 Health concerns related to contaminants

There is evidence that environmental changes caused by warming temperatures result in an increased release of contaminants into the environment, with potential impacts on human and environmental health. Thawing permafrost, and melting glaciers and sea ice can release stored contaminants into the Arctic environment (Obbard et al., 2014). For example, it is estimated that 793 million kilograms of mercury could be released from thawing permafrost in the Northern Hemisphere permafrost regions over the next century (Schuster et al., 2018). Elemental mercury is transformed by aquatic algae into methylmercury, which is more toxic and bioavailable, and is the predominant form of mercury found in fish and the marine environment (Miner et al., 2021). Projected increases in algal growth in Arctic lakes, occurring concurrently with mercury being released from thawing permafrost, will likely result in increased methylmercury in the aquatic environment. Thawing permafrost and decreased snow cover may enhance the release of radioactive radon-222 from the soil, resulting in increased environmental levels of lead-210 and polonium-210, which are both toxic radioactive substances (Arctic Monitoring and Assessment Programme, 2010). Radionuclides and mercury may also be redistributed from natural events such as wildfires, which are projected to increase in frequency and intensity with climate change (Wang et al., 2017).

The threat of increased release of contaminants in the Arctic has serious consequences for the Arctic environment and wildlife populations, with subsequent health impacts on humans when consuming wild foods (including land animals, birds, fish and sea mammals and foraged foods) with elevated levels of contaminants. Precautionary measures include the issuance of advisories by provincial or territorial health authorities related to the consumption of foods linked with health risks. For example, a health advisory in Nunavut recommends that women of child-bearing years avoid eating ringed seal liver due to high concentrations of mercury. Concerns around consuming contaminated country foods could result in increased reliance on market foods, which can be less nutritious, more costly and a potential maladaptation (Rosol et al., 2016; Berry et al. 2014).

6.3.5 Health risks from wildfires

While there is little synthesis of knowledge from which to create a wildfire-associated risk framework in Canada (Johnston et al., 2020), many Indigenous communities in Canada are at higher risk from wildfire because of their remote locations and close proximity to forests (Christianson, 2015). From a human health perspective, wildfires may result in death, trauma and major burns (Cameron et al., 2009), post-traumatic stress disorder symptoms (Papanikolaou et al. 2011; McDermott et al., 2005) and mental health problems (*see* Sector Impacts and Adaptation chapter of the National Issues Report; Coogan et al., 2019). Smoke distribution can be significant far beyond the immediate vicinity of a fire (Reid et al., 2016), compromising air quality even for distant populations (Henderson and Johnston, 2012).

Recent extreme wildfire events include the 2014 fire season in the Northwest Territories, where drought conditions resulted in 3.4 million hectares of land being affected by 385 separate fires. The cost of fighting those wildfires was $56.1 million—almost eight times greater than the territory's annual firefighting budget at the time (Dodd et al., 2018). The fires caused evacuations from communities throughout the territory, serious health consequences and respiratory distress, and ongoing fear and anxiety among Indigenous and non-Indigenous Northerners. Many people reported mental, emotional and spiritual tolls, and having feelings of isolation as a result of staying indoors in compliance with public health advice or due to forced evacuation, and because of loss of time on the land (Dodd et al., 2018). People also reported feeling anticipatory stress and grief about possible future wildfires and further impacts to place and environment, communities, physical health, food security, and mental and emotional health (Dodd et al., 2018).

6.4 Safe travel in the North is threatened by climate change

Climate change is increasing risks to safe travel in the North, but drawing from different types of knowledge is helping to reduce these risks.

Decreasing ice cover, as well as changing landscapes and weather patterns, are impacting travel in the North. In some cases, adoption of new technology can increase vulnerability by placing reliance on things such as cellphone or satellite connectivity, or electronic vehicle components. Northern residents have developed innovative solutions that are specific to the needs in the region. The tools used to exchange knowledge of local conditions are helping Northerners to better prepare for conditions that are outside the range of previous experience.

6.4.1 Introduction

Northerners recognize that changing environmental conditions and weather patterns are resulting in increased risk to safe travel on the land, ice and water, and by air. While climate change affects physical trails or routes through, for example, loss of ice or permafrost thaw, key factors that enable access to the land include maintaining confidence in Indigenous Knowledge, access to equipment (ranging from reliable vehicles to radios and cell phones) and risk tolerance (Ford et al., 2019; Harper et al., 2015). The loss of access to land-based activities negatively impacts physical and mental health, and adaptation measures are an effective way to improve resilience (*see* Rural and Remote Communities chapter of the National Issues Report; Durkalec et al., 2015). Travel-related climate change impacts increase risks to human life, impact property and wellness, and put pressure on search and rescue operations that sometimes have limited equipment and training appropriate to changing conditions (Ford and Clark, 2019). While boats, all-terrain vehicles (such as quads/4-wheelers and side-by-side vehicles), snowmobiles, trucks and other means of transportation all form integral parts of life in the North, increased risks from climate change are leading Northerners to assess their own risk tolerance and to develop strategies to limit risks.

6.4.2 New dangers threaten Northern knowledge of safe travel

Travel in northern regions is part of life (*see* Case Story 6.3). In areas where communities are small and distributed over large areas, travel to access the land, services and education and to conduct business is essential. In some regions, both ice-based and land-based trails are necessary for travelling between communities (Durkalec et al., 2015; Ford et al., 2013; Aporta, 2011). For many Northerners, hunting and travelling on the land and water play a vital role in ensuring food security and maintaining cultural identity (Cunsolo Willox et al., 2013a; Laidler et al., 2008). Land-based and water-based recreation and traditional pursuits, often in remote areas, occur through all seasons. Air travel is also critical to northern communities that rely on aviation for the transportation of people and essential goods and services, and for accessing health care (Government of Canada, 2017). However, travel-associated risks driven by changes in climate, like reduced ice thickness, shifting ice freeze-up and break-up dates, thawing permafrost, unpredictability of weather patterns and extreme events are impacting both perceived and actual safety of all modes of northern travel (Ford et al., 2019).

Case Story 6.3: Perspective on risks to public safety in Makkovik, Nunatsiavut

The following is an excerpt from Winston (Barry) Andersen, a resident of Makkovik, Nunatsiavut, who serves in search and rescue operations, describing his experience with changing climate and how it has impacted public safety in his community:

"[I] spent all my life working, travelling, gathering, cutting firewood, picking berries, hunting and fishing in Nunatsiavut. For sustenance purposes only. Never fished or trapped commercially. Trap fur-bearing animals for my personal use… I have travelled northern Labrador from Makkovik area to Nain area and inland from Nain to the Quebec border by snowmobile hunting caribou. I have also travelled from Makkovik area to Nain by boat during the summer months both personally and for work as a guide for DFO [Department of Fisheries and Oceans]. With the RCMP, [I] was a guide in the Makkovik, Hopedale and Postville areas. On my first trip to Nain via snowmobile, I was 16 years old and travelled with my father and uncles, learning from them along the way by observing and some lecturing while on the land, or simply sitting in a tent and listening to the elders talking about the weather signs, ice and snow conditions. I travelled from Makkovik to Davis Inlet and inland to Border Beacon in winter and spring, caribou hunting.

Over the last 30 years, I have experienced a major change in the weather patterns. This is also observed by my father and many other elders in my community. Once predictable weather patterns during all seasons are now very unpredictable. In the Makkovik area, the prevailing winds in the spring and summer would be variable. Mornings would be calm, mostly westerly winds during the daylight hours and calm in the evenings. Summer would see long stretches of clear weather with thunderstorms intermittently. Fall would see more northerly winds causing sea swells to rise. The elders would always say in late August or early September it was time for the "liner gale": a strong storm with either northerly or northwest winds and rain that lasted for about three days. After this storm was over, things would settle down. More storms would follow, but they were not as intense. In the winter, the prevailing winds were from the west with cold temperatures.

Today, we see more extreme variable weather causing problems for hunters, trappers, fishermen and travellers generally. In the springtime, we are seeing the sea ice break up earlier. Sometimes now in mid-May the ice is not safe to travel on by snowmobile. In the winter months, the sea ice is also not as stable as it once was along the Labrador coast. Freeze-up is later into December and early January as opposed to early December in years past. Strong winds at sea rises sea swells breaking the ice and disrupting snowmobile travel by leaving open water in areas where the snowmobile trails should be. Sea ice in sheltered bays is static and doesn't move around with the tides as it does at the head lands where the ice can break loose and flow south in the Labrador Current. Simply going out on the sea ice to hunt seal at the sina [the edge of the ice, similar to a polynya] can be dangerous. If the sea swell rises and you are not aware, the ice you are on can break off and begin to drift away. Nobody has been lost due to this, but snowmobiles have been lost in the past due to this kind of event. In the past, heavy slob (snow and water mixed) at sea formed by drifting snow into the ocean and cold temperatures would be six to eight feet thick. This would dampen the sea swells before it reached close to shore. It was a barrier of sorts that gave us some protection. With today's warmer climate, we do not see this effect very often. These variable and extreme weather patterns cause serious safety concerns for users of the land. Many people have gone missing or were stranded for long periods of time due to unforeseen weather and poor snow/ice conditions, or in summer, very high winds and large sea swells."

– Winston (Barry) Anderson, personal communication, 2018

The dangers involved with travelling on the land are linked to the ability of northern Canadians to be food secure and to earn their livelihoods, while the inability to participate in cultural activities severely impacts mental health and wellness (Cunsolo Willox et al., 2013a; Laidler et al., 2008). For example, unsafe sea ice conditions near a coastal Nunavut community may prevent a parent and child from travelling to harvest seal, reducing their access to country foods and the income potential associated with skins, clothing and arts products derived from the animal. The parent also loses their opportunity to share knowledge with their child. In some cases, changes to the land and water, including ice, are resulting in personal injury and damage to, or loss of, equipment like snowmobiles; in the worst cases, they are leading to loss of life.

Arctic communities are experiencing the impacts of sea ice loss in ways that are not always documented in academic literature (Ford et al. 2016; Cuerrier et al., 2015; Wenzel, 2009). These include greater risks for travel across sea ice and open waters, as well as increased marine traffic as a result of better navigability and a longer open-water season. Reduced ability to anticipate suitable sea ice conditions make travel slower, more complex and less safe (Ford et al., 2019; Bell et al., 2014, Nickels et al., 2005). Increased open-water conditions have resulted in rougher water, more fog, difficulty accessing certain safe harbours due to rapid coastal erosion, and movement of sediment (formerly protected by sea ice and permafrost) (Nickels et al., 2005).

Declines in Arctic sea ice have resulted in an increase in navigability and open-water season length for marine traffic (*see* International Dimensions chapter of the National Issues Report; Melia et al., 2016; Pizzolato et al, 2014; Smith and Stephenson, 2013; Stephenson et al., 2013). Since 1990, the distance travelled by ships through the Canadian Arctic has increased threefold (Dawson et al., 2018), with the largest increases attributed to bulk carriers, passenger ships (cruise ships) and pleasure craft (yachts). In addition to climate change impacts, non-climatic factors—such as global economic trends; demand for natural resources related to mining, fisheries, trade, and tourism; demographics; construction demand; and commodity price variability (Pelletier and Guy, 2012)—also influence ship traffic in Arctic waters.

The largest increase in ship traffic has occurred in the eastern Canadian Arctic around Baffin Island, Hudson Strait and the southern route of the Northwest Passage (Dawson et al., 2018). Several communities have experienced significant increases in ship traffic over the past decade, including Pond Inlet, Baker Lake, Cambridge Bay and Chesterfield where there have been recent or ongoing mining and tourism activities (Dawson et al., 2018). It is important to note, however, that factors such as lack of infrastructure and modern bathymetry charts, harsh weather conditions, remoteness and lack of broadband communications will still limit the potential for long-term growth of shipping in the Canadian Arctic in the near-term future (*see* International Dimensions chapter of the National Issues Report; Farré et al., 2014; Smith and Stephenson, 2013).

Combining Indigenous Knowledge, local knowledge and technology can help to reduce challenges and dangers associated with travelling by sea in the face of a changing climate. Innovative examples of this include SIKU.org, an Indigenous Knowledge Social Network that provides an online platform with specific provisions for securing and protecting Indigenous Knowledge, while helping to inform travel decisions and monitor environmental observations (Arctic Eider Society, 2019). Another example is SmartICE (*see* Figure 6.9; SmartIce, 2022) a northern social enterprise that provides employment opportunities related to data gathering and instrument development and production, along with an online platform for presenting data and augmenting Inuit knowledge, all while also helping to strengthen Inuit culture and support intergenerational teaching (Bell et al., 2014). These tools often work together. For example, SmartIce feeds directly into SIKU.org. The Floe Edge Service is a Web-based portal providing community members with access to satellite

imagery of ice conditions, which is updated three to five times per week (Laidler et al., 2011). Each of these examples provides easy access to a range of information sources so that travel plans can be made with better foreknowledge of local conditions and can be adjusted accordingly.

Figure 6.9: SmartICE is a community-based social enterprise offering climate change adaptation tools and services that integrate Inuit knowledge of sea ice with monitoring technology. This is a photo of SmartICE researchers Samuel Dicker (left) and Rex Holwell (right). Photo courtesy of SmartICE and Hamlin Lampe, 2022.

Other adaptation actions reducing risk to travel on land, water and ice include enhanced surveillance and early warning systems that alert community members to incoming adverse conditions, the bolstering of local search and rescue operations to respond in emergency situations, and enhanced emergency preparedness education (Ford et al., 2014). In multiple Nunavik communities, hunters, Parks Canada, and the Kativik regional government have invested in developing a new VHF radio network that has improved the ability of community members to share information about on-the-land conditions and travel plans (Anselmi, 2019). An Indigenous-led initiative is installing weather stations in multiple communities along the Labrador coast. The active stations at Rigolet, North West River, Red Bay and Postville, as well as future planned stations, will help to fill the gaps in weather monitoring data for the area and to improve the accuracy of weather reports, which can be a matter of life and death to northern Canadians in the area (Careen, 2019). Growing these networks and subsidizing the cost of personal radios are important aspects of addressing real and perceived risks of northern travel (Shah et al., 2018).

While new technologies are often regarded as adaptation solutions, their adoption can sometimes exacerbate or compound travel risk in northern regions. For example, the use of electronic technology in snowmobiles

and small watercraft engines increases the risk of water-induced damage and reduces reparability in the field. New four-stroke engine snowmobiles with electric starters are not typically equipped with backup starters due to high compression. Thus, a problem in an electrical relay or computer module can leave a traveller stranded (Andersen, 2018).

Ice roads (roads entirely on ice) and winter roads (roads on both ice and land) are important conduits for importing materials and supplies to some northern communities and mines, but shorter winter seasons and changes to lake and river freeze-up and break-up dates can impact operating season and stability (Pendakur, 2016; Andrey et al., 2014). The operating season length of an ice road has an immediate economic impact on the mines and communities relying on them. Supplies that cannot be moved on the ice road may have to wait to be transported by barge (where available) or by air (at significant cost). Ice roads are particularly vulnerable to climate changes such as temperature swings in excess of 18˚C, the number of consecutive days above 0˚C, the amount of snow on the ground as of January 1st and the number of extreme cold events during the operational season (Perrin et al., 2015). These changes necessitate adaptation actions, which include the use of new technologies and construction techniques, as well as increased maintenance and monitoring (Pendakur, 2016).

Ice bridges (e.g., seasonal crossings over a frozen river to connect all-season roads) are also key to some northern highways. The Dempster Highway, which stretches for 740 km from Dawson City, Yukon, to Inuvik, Northwest Territories, crosses several streams and includes crossings of the Peel and Mackenzie Rivers, which operate as ferry crossings in the summer and ice bridges in the winter. To mitigate the shortening of the ice bridge season, the Government of the Northwest Territories has constructed several permanent bridges over stream crossings. Ice spray, a technique that sprays river water into the air over the river during freeze-up, applied at the Mackenzie River crossing helps to develop thicker ice earlier in the season, and ground-penetrating radar is used to measure ice thickness and to identify thin sections (Government of Northwest Territories, 2008).

Operational and policy changes have been implemented to consider changing winter road conditions in the Northwest Territories. For example, the Northwest Territories Housing Corporation began awarding contracts to suppliers one month earlier to allow for adjusted transport schedules, including load adjustments in response to road weight limitations (Government of Northwest Territories, 2008). Residents living north of the Peel and Mackenzie Rivers also stockpile additional supplies and fuel in anticipation of a longer period of road closure between the ferry and ice-bridge seasons, but not everyone can afford the up-front cost of purchasing enough supplies to span this period. Climate change also affects the viability of permanent, all-season roads in the North, and is increasingly being incorporated into long term planning and management processes (*see* Case Story 6.4).

Case Story 6.4: Improving the climate resilience of the Dempster Highway

Engineers and maintenance personnel typically use planning tools, such as functional plans, to provide high-level summaries of anticipated maintenance, safety, and engineering needs and associated costs. In an innovative project, Yukon Government's Department of Highways and Public Works developed a functional plan with a 25-year outlook for the Dempster Highway that explicitly considers climate change impacts on geohazards as an integrated part of the plan (Associated Engineering, 2018; Calmels et al., 2018).

The Dempster Highway, which is the only highway linking Yukon and the Northwest Territories, is experiencing climate change-related impacts, including permafrost thaw, flooding and active layer detachments following extreme precipitation (*see* Figure 6.10). Snow drifting, washouts due to flooding, retrogressive thaw slumps, culvert failures and subsidence due to the melting of ground ice are key concerns that the Highways and Public Works Department is attempting to anticipate and address in the context of climate change. Highways and Public Works considered projected changes to hydrology, as well as detailed characterization of permafrost thaw vulnerability, as inputs to their functional plan. This approach builds consideration of climate change directly into a commonly used planning tool and exemplifies an innovative approach to ensuring that a full suite of risks are being considered in maintenance and engineering decisions for the highway.

Figure 6.10: Photo of the Dempster Highway following a heavy rainfall event in August 2022. Photo courtesy of Meredith Caspell.

Climate change is likely to have varied impacts on aviation in northern Canada, including more frequent and lengthier weather-related delays, increased clear-air turbulence and modified flight times due to increased winds (Storer et al., 2019; Williams and Joshi, 2013). Andy Williams, a bush pilot who has been flying over the ice fields in Kluane National Park since the 1970s, reports that the region has experienced "incredible amounts of change," including changes to snow conditions necessary for take-offs and landings (Hossack, 2018).

Limited local weather information contributes to the delay and cancellation of flights—for example, in 2015, approximately 29 % of Nunavut's medical emergency evacuations were cancelled or delayed due to lack of reliable weather reporting (Government of Canada, 2017). Coverage by automated weather observation systems, which provide continuous, real-time information about weather conditions, is limited across the North, as the construction and networking of stations are costly (Hatt, 2016). Initiatives such as the Meteorological Service of Canada's Collaborative Monitoring Initiative are helping to improve access to data to ensure that it can be used in forecasting, and are working to increase understanding of weather and climate systems (Zucconi and Karn, 2019; Hatt, 2016).

The ability to safely travel on the land relies on many factors, not all of which are climate-related. For example, social determinants, such as knowledge of routes and expected conditions, access to well-maintained equipment, and time to wait out a storm, all contribute to travel safety regardless of conditions (Clark et al., 2016a). While climate change is impacting seasonality of trail use, there is conflicting evidence regarding whether useable seasons are actually shorter. In addition, non-climate factors can also play a role in travel safety. For example, the cost of safety equipment and reduced transmission of land skills to younger generations were dominant factors affecting search and rescue operations along Canada's Arctic Coast between 2013 and 2014 (Ford et al., 2019).

6.5 Northerners are leaders and innovators in climate change adaptation

Innovative approaches to governance, policy and development are addressing social inequities and opening pathways for collaborative and inclusive climate change adaptation.

Northerners are exerting greater influence over decision-making and the building of climate change resilience through the development of innovative policy approaches and pragmatic infrastructure management. Central themes in successful adaptation initiatives include drawing from Indigenous Knowledge and a culture of self-sufficiency and local problem solving. Within the unique governance environment in northern Canada, where many Indigenous communities are self-governing, Indigenous-specific policy spaces are foundational to good governance and are laying the groundwork for innovative approaches to planning and decision making. While economic opportunities may enhance resilience and provide additional adaptation options, modern governance approaches can provide the basis for cautious and careful exploration of the costs and benefits related to these emerging opportunities and their potential impacts on northern people, societies and cultures, and environments.

6.5.1 Devolution and Indigenous self-determination

The implementation of modern treaties and the devolution of some aspects of governance by the federal government have led to greater self-determination, and the ability of Indigenous and non-Indigenous Northerners to play a greater role in leading decision making, including that associated with climate change adaptation actions (Alcantara et al., 2012). While not typically conceived of as a climate change adaptation action, devolution in northern regions (i.e., the delegation of certain federal decision-making authorities to the territorial governments) has resulted in regional governments having greater authority over actions in their regions, thereby improving the resilience of smaller governments because they are better able to respond to the needs of their members, and also increasing their ability to plan for anticipated changes (Coates and Broderstad, 2020).

Increasing the inclusion of local communities and Indigenous Peoples in decision making, and strengthening governance mechanisms to support the goals of self-determination, have helped community development to succeed in the face of increased socioeconomic growth (Ritsema et al., 2015). Progress towards more meaningful inclusion of Indigenous worldviews contributes to more consideration of the holistic interrelationships between nature and society (*see* Case Story 6.5)—expanding the opportunity to consider and build resilience to climate change impacts.

Case Story 6.5: Excerpt from "Indigenous Governance as an Adaptive Climate Change Strategy"

Indigenous Peoples provide critical insights into how climate change results in immediate and important implications for humans (Alam, 2018). However, using Indigenous experiences as evidence for climate change often is where the conversation stops.

In academia, where much of the thinking on climate change adaptation originates, much has been made of Indigenous responses to climate change framed as "resilience" (i.e., "Don't worry, Indigenous Peoples will bounce back"; Ramos-Castillo et al., 2017) or "ecological grief" (i.e., "Worry, Indigenous Peoples cannot bounce back and this grief amplifies other social ills"; Cunsolo, 2012). Such analyses provide compelling evidence for action, yet also paint a picture of peoples at the margins of power.

The only legitimate and probably sustainable climate change adaptation strategy for Indigenous Peoples starts with their continuing to know and understand their lands through being on and living with their lands, even if power over land management or weather eludes them. Like many of the pressures faced by Indigenous Peoples, their climate change adaptation options are subject to settler colonial, societal and institutional control. The best climate change adaptation strategy is for governments (and voters) to support Indigenous governance of climate change strategies for their communities and territories, ensuring the provision of resources needed to accomplish targeted outcomes and goals.

Using the power and authority over their lands and people, recognized through negotiated rights-based agreements and/or rooted in cosmologies that understand Indigenous Peoples as part of their lands, many

Indigenous governments have undertaken targeted, culturally based land connection initiatives. These range from building land-based camps for uses from eco-tourism to healing, to major annual seasonal journeys through their traditional territories, as ways to reconnect youth to their people and identities. These land-based acts are generative of identity and relationship, and are essential for closing the various gaps and healing the individual and collective harms resulting from ongoing colonial impacts. Labelled by Indigenous scholars as "grounded normativity" (Coulthard and Simpson, 2016), simply put, it is the ability for Indigenous people to engage in cultural resurgences and forms of culturally based being as the basis for their social and political norms.

A fundamental requirement for enacting Indigenous governance as an adaptive climate change strategy is for settler colonial society to get out of the way: to respect Indigenous land relationships, to honour Treaties through fulfilling legal obligations, to restore governance authorities and to institute specific actions for restoring respectful societal relations, as recommended by Truth and Reconciliation Commission of Canada, 2015 (Truth and Reconciliation Commission of Canada, 2015b). Climate change adaptation on these terms would support Indigenous Peoples to lead us all in adapting to climate change on the lands that they have managed since time immemorial.

Source: Irlbacher-Fox and MacNeill, 2020.

6.5.2 Impact assessment and co-management

Co-management boards and decision-making bodies engaged in impact assessment in many jurisdictions in northern Canada have created a network of knowledge holders and practitioners who are well-versed in interpreting Indigenous Knowledge, science and other forms of information that enhance decision-making processes. Co-management (*see* Box 6.3) and shared approaches to impact assessment facilitate culturally appropriate environmental protection in the hope of maximizing both socioeconomic and environmental resilience, including resilience necessitated by the impacts of climate change.

Box 6.3: What is co-management?

Co-management arrangements in Canada, as established under modern-day land claim agreements (for example, the *Nunavut Land Claims Agreement Act* and the *Western Arctic (Inuvialuit) Claims Settlement Act*), are formal and legally-based cooperative institutional arrangements among provincial, territorial and federal governments, Indigenous authorities and, in some cases, local "user" communities. There is significant regional variability regarding precisely how power is shared among the parties at a co-management table, and how well formal agreements are implemented and followed, with some describing co-management as cooperative management due to region-specific interpretation of how power sharing is being implemented (Clark and Joe-Strack, 2017). However, co-management partners are generally required to give equal weight to Indigenous Knowledge and science in their recommendations and decisions affecting wildlife management (Minister of Justice, 1993; Minister of Indian Affairs and Northern Development, 1984). Within

the context of climate change, co-management boards draw on diverse experience and expertise related to research, decision making and policy as they relate to protecting animals, plants and fish that are particularly vulnerable to climate change. Through this collaborative structure, co-management boards provide a "shared space" where all levels of government agree to work together in specific geographic areas; outside of those areas, each organization retains its respective powers and jurisdictions (Snook et al., 2018).

At the regional scale, a key strategy for maintaining ecosystem and social resilience encompasses conservation and resource management efforts that maintain large natural landscapes with a diverse array of habitat types and connectivity. Key adaptive measures that are already being implemented include the following: continuing and improving co-management and adaptive management by local, territorial, federal and international partners; recognizing spatial and temporal variability in species response to climate change; implementing monitoring programs with clear goals; reducing cumulative impacts of increased human activity; and recognizing the limits of current protected species legislation (Laidre et al., 2015). These efforts allow for managing potentially impactful activities in ways that reduce changes in vulnerable ecosystems and maintaining mechanisms of resilience that give rise to healthy, dynamic landscapes (Chapin et al., 2006; Walker et al., 2004).

Similarly, strategic-level mechanisms (e.g., regional impact assessments, regional land use plans) are critical for addressing complex issues, such as the assessment of climate change impacts, including cumulative impacts, which extend beyond the individual project level. For example, the North Yukon Regional Land Use Plan undertook a scenario modelling approach that examined potential impacts from climate change and energy sector activity on caribou habitat (Francis and Hamm, 2011).

Few strategic-level or regional-level assessments address the cumulative impacts of climate change in Canada (Blakley et al., 2020), let alone for the North. A range of issues must be considered to ensure that these processes are effective, and that they include the concerns of Indigenous communities in the North about strategic-level issues leading to a loss of power or control in their relationship with the federal government (Fidler and Noble, 2013). Regional land-use plans are a mechanism that is implemented more frequently, but generally speaking, such plans do not address cumulative impacts of climate change. The above example of the North Yukon Plan is notable in that it attempted to incorporate cumulative impacts and climate change considerations in its development process. Similarly, the Strategic Environmental Assessment in Baffin Bay and Davis Strait, the final report of the Nunavut Impact Review Board, examined development scenarios in the context of cumulative impacts and climate change considerations. Importantly, the report notes that "this assessment has made significant progress with the respect for and treatment of Inuit knowledge and experience" (Nunavut Impact Review Board, 2019, p iii).

Monitoring is a key enabler in both impact assessment and strategic-level assessment. Initiatives to consolidate access to data (e.g., the open data portal launched by the Government of Yukon, 2020) and the Northwest Territories Cumulative Impact Monitoring Program (Northwest Territories Cumulative Impact Monitoring Program, 2015) are examples of initiatives that improve the accessibility to, and effectiveness of, public data. Increasingly, co-management institutions require innovative and streamlined processes to stay informed about the rate and types of changes in habitat conditions (Lenton, 2012; Chapin et al., 2010;

Beaufort Sea Partnership, 2009). This information is used to re-assess and establish habitat protections early enough to be effective (Chapin et al., 2010; Beaufort Sea Partnership, 2009).

Co-management arrangements need up-to-date information and expanded knowledge on ecosystems in Canada's North, and on how they are responding to climate change (Staples, 2013). For example, when species that were previously considered incidental or invasive become frequent visitors or residents (*see* Section 6.2), the current understanding of ecosystem integrity is challenged and the functioning of Arctic marine food webs must be reassessed (Staples, 2013). Indigenous Knowledge and local knowledge from subsistence users and communities, and input from regional institutions that monitor and report on ecological and sociological changes, will be important for co-management arrangements to continue their work in ensuring ecosystems in Canada's North are resilient in the face of climate change. Expanding the mandate of co-management agreements may also be required in order to maintain their effectiveness in the face of climate change (Popp et al., 2018; Snook et al., 2018; White, 2018).

Co-management boards are also leading efforts to ensure that Indigenous Knowledge and local knowledge informs decision making. This is distinct from including Indigenous membership. The observations and knowledge of Indigenous Peoples and local people provide current information that can identify subtle changes in species health and ecological conditions (Gearheard et al., 2011; Berkes et al., 2007), which can help to inform responsive management practices (*see* Case Story 6.6). In this way, co-management boards play an active role in facilitating dialogues that incorporate both Indigenous Knowledge and science related to climate change adaptation and changes to food systems, livelihoods and well-being, and serve as platforms for adaptation actions. Co-management boards help to ensure that the voices, knowledge and science of the region are meaningfully included in climate policy analysis, and that adaptation initiatives continue to be enhanced through co-learning, cooperation and the implementation of co-management recommendations and decisions.

Case Story 6.6: Co-management approaches to polar bear management

Canada is home to thirteen of the world's nineteen polar bear sub-populations. It collaborates internationally with other nations with large polar bear populations. Polar bears (*Ursus maritimus*, "*nanuq*" in Inuktitut) are a keystone species and have received increasing attention within the context of climate change and environmental shifts. This species is designated as a species of "special concern" by the Committee on the Status of Endangered Wildlife in Canada, with a predicted decline over the next three decades due to a reduction in seasonal ice coverage (The Committee on the Status of Endangered Wildlife in Canada, 2018).

Shorter ice seasons and less stable ice conditions already affect harvesters' access to polar bears (Joint Secretariat, 2015; Hovelsrud et al., 2011). This has led to adjustments in the length of the period within which hunters are permitted to harvest an animal. As a result, co-management partners must balance the demand for fewer licenses held for longer periods of time with reduced hunting opportunities for all harvesters. In some instances, these types of changes require a re-assessment of long-standing regulated harvest seasons.

Within Canada, there are multiple levels and structures of government that collaborate on polar bear management, including the Government of Canada, the provinces and territories, the national Polar Bear Technical Committee, the Polar Bear Administrative Committee, and a network of co-management boards in Inuit Nunangat that were established through negotiated land claim agreements. These boards are undertaking research, leading dialogues and making decisions at the local level in Inuvialuit, Nunavut, Nunavik and Nunatsiavut. These collaborative efforts are making substantive contributions to knowledge about polar bears and are also helping to integrate Inuit *Qaujimajatuqangit* into decision making and recommendations. Inuit *Qaujimajatuqangit* is defined as "all aspects of traditional Inuit culture including values, worldview, language, social organization, knowledge, life skills, perceptions and expectations" (Government of Nunavut, 1999). For example, in 2010, the Government of Nunavut started publishing supplemental Inuit *Qaujimajatuqangit* that supported and influenced dialogues about polar bears (Kotierk, 2010a,b). Nunatsiavut and Inuvialuit followed suit in 2015 (Joint Secretariat, 2015; York et al., 2015), as did Nunavik in 2018 (Nunavik Marine Regional Wildlife Board, 2018). Through the generous sharing of their knowledge, Inuit enhance polar bear management within Inuit communities, national organizations and internationally (Clark et al., 2013).

6.5.3 Energy security and community resilience

Much of the electricity infrastructure in northern Canada was built when considerations of climate change and other factors were not as prominent as they are today. Currently, energy security for Canada's northern communities is an area in which economic development, innovations in policy and governance, applied research, and community capacity development are contributing to resilience (Bizikova et al., 2008). As ageing energy infrastructure is replaced, and increasing value is placed on limiting negative socioeconomic and environmental impacts, governments, industry and communities are beginning to turn to new approaches for energy production (Natural Resources Canada, 2018). Today, electricity is primarily generated through a combination of hydroelectric power and diesel generation, with the growing use of solar energy and other alternatives like liquefied natural gas and biomass (Canada Energy Regulator, 2019). Wind and geothermal power generation are also being explored.

Capacity-building initiatives to increase energy security and resilience include training programs and project funding. Examples include the 20/20 Catalyst Program, a three-month program designed to build leadership skills and project management capacity of Indigenous community members, and the Arctic Community Energy Planning and Implementation Toolkit, a publicly available resource for northern communities developing and implementing community energy plans and project (Indigenous Clean Energy Social Enterprise, 2019; Cox et al., 2019). Increasingly, communities are recognizing the impact that local energy coordinators can have in developing tools and projects by creating capacity to pursue funding for and to coordinate community-oriented projects and programs associated with energy security (Denton et al., 2015). Applying these approaches to energy projects allows northern communities to harness local knowledge and social capital, incorporate unique circumstances, values and challenges on a community scale, and build resilience to climate change within their energy systems while providing environmental, health, social and resilience benefits.

In Aklavik, Northwest Territories, the efficiency of variable speed generators in a range of northern operating conditions and loads is being tested as a way to optimize the use of diesel that is normally brought to the community by sea lift, acknowledging that diesel power is likely to remain an important resource for remote communities (Yukon Research Centre, 2019; Mercer et al., 2018). In some Nunatsiavut communities, energy plans have prioritized the efficient use of diesel for heat and power generation as a familiar, reliable and predictable energy source that provides employment benefits. This highlights how adaptation and resilience are improved by investing in existing infrastructure, while acknowledging that emission reduction benefits are sometimes outweighed by the benefit of maintaining a known technology (Mercer et al., 2018).

In parts of the North, hydropower is already an important source of electricity. Increasing streamflow associated with climate change may prove to be beneficial for hydropower generation. However, increasing flow variability and changes to the timing of peak and low flows can add uncertainty and challenges for sustained power production (Gaudard et al., 2013). By understanding how changes to streamflow may occur on different timescales, hydropower corporations can better adapt their short-term operations to ensure that they meet energy demands in the coming year, and can improve their long-term planning. Streamflow forecasting tools, such as those being used by the Yukon Energy Corporation, can help decision-makers understand how changes to streamflow may occur on different timescales (Samuel et al., 2019).

Within communities, synergies often exist between climate change resiliency and community-led projects. In Inuvik, Northwest Territories, a 5-kW grid-tied solar photovoltaic system was installed in 2017 for the Inuvialuit Community Economic Development Organization's community freezer project as part of a four-day solar energy workshop (Inuvialuit Regional Corporation, 2017). The workshop increased the community's food security and technical capacity related to renewable energy, while also supporting traditional hunting practices and contributing to the community's transition towards energy independence (Arctic Energy Alliance, 2020). In this example, local practices and knowledge were supported and utilized through the development of working relationships between local, regional and national organizations to improve the local community's food and energy security.

The development of responsive energy policy also offers another example of how policy innovation can support climate change adaptation, low-carbon resilience and energy security. While northern energy policies and regulations have historically been applied territory- or province-wide, independent power producer and net metering policies have allowed individual communities to lead their own energy projects (Karanasios and Parker, 2016). The governments of the Yukon and the Northwest Territories have both developed policies that incentivize communities and entrepreneurs to produce energy via renewable energy sources and to feed it back into electrical grids with compensation (*see* Case Story 6.7; Government of Northwest Territories, 2018; Government of Yukon, 2018). The Government of Nunavut launched a net metering policy in 2018 and is currently developing an independent power producer policy for the territory (Quliq Energy Corporation, 2020, 2018). In Nunavik, Pituvik Landholding Corporation has signed a Power Purchase Agreement with Hydro Quebec for the construction of a 7.5-MW hydropower plant (Innergex Renewable Energy, 2019). When developed effectively, energy policy can improve community resilience by enabling leadership and adaptation at the community level.

Case Story 6.7: The Old Crow Solar Array

The Vuntut Gwitchin First Nation wanted to improve energy security and reduce reliance on diesel needed to fuel generators, which was being flown into the community of Old Crow, Yukon's northernmost community. However, there was uncertainty regarding the technical constraints of the existing electricity infrastructure. Conflicting reports from consultants and companies created uncertainty about the possibility of including solar power in existing infrastructure owned by ATCO Electric Yukon. The Vuntut Gwitchin Government approached Yukon University's Northern Energy Innovation research team to receive technical assistance from an independent third party. With the participation of both ATCO Electric Yukon and Vuntut Gwitchin Government, the team conducted a power system impact study of Old Crow's electrical grid to determine if and how the renewable resource could be integrated into the system to provide a stable and reliable energy source. The study provided a basis for Vuntut Gwitchin Government to move ahead and implement its vision for greater energy security and low-carbon resilience (Arctic Council Secretariat, 2022).

Concurrently, the Yukon Government developed an independent power producer policy that allows communities to generate electricity and sell it to existing grids (Government of Yukon, 2018). The community of Old Crow can now operate without the use of diesel for 95 to 100 non-consecutive days of the year. While the Vuntut Gwitchin Government purchased the capital assets for the solar energy plant, ATCO continues to ensure that the energy produced by the solar panels is stored in batteries, and properly and safely utilized to provide a consistent and reliable energy source. The success of this project was enabled through a coordinated and collaborative effort by the private sector, governments and academia.

6.5.4 Community responses to biophysical change

It has been estimated that climate change impacts on public infrastructure in the Northwest Territories will cost $1.3 billion over the next 75 years (Northwest Territories Association of Communities, 2018), providing a general understanding of the anticipated costs of climate-induced damage and advantages of applying adaptation actions. The Canadian Climate Institute is currently conducting a pan-northern analysis to estimate the financial impacts of permafrost thaw on infrastructure (Clark et al., 2022).

Recognizing the urgency of permafrost thaw-related infrastructure issues, the Standards Council of Canada's Northern Infrastructure Standards Initiative (NISI) has initiated work to prepare a guide for hazard mapping. NISI and the *Bureau de normalisation du Québec* (BNQ) have made northern-specific guidance available for moderating the effect of permafrost on foundations (Standards Council of Canada, 2014a), managing snow loads (Standards Council of Canada, 2014b), thermosyphon foundation design (*see* Figure 6.11; Standards Council of Canada, 2014c), community drainage design (Standards Council of Canada, 2015) and geotechnical site investigation (*Bureau de normalisation du Québec*, 2017). These tools assist decision-makers, but the costs of implementing the recommended measures and accessing qualified experts are barriers to their implementation. To encourage uptake of these resources, NISI has partnered with northern organizations to develop posters and "101-style" videos that summarize each standard and provide the key points for community infrastructure managers (Standards Council of Canada, 2020a). Northern organizations

are playing a more prominent role in the review and revision of existing standards, and creation of new ones. However, standards to quantify permafrost vulnerability to thaw are not broadly established or practiced (*see* Section 2.1.2; Arctic Development and Adaptation to Permafrost in Transition, n.d.).

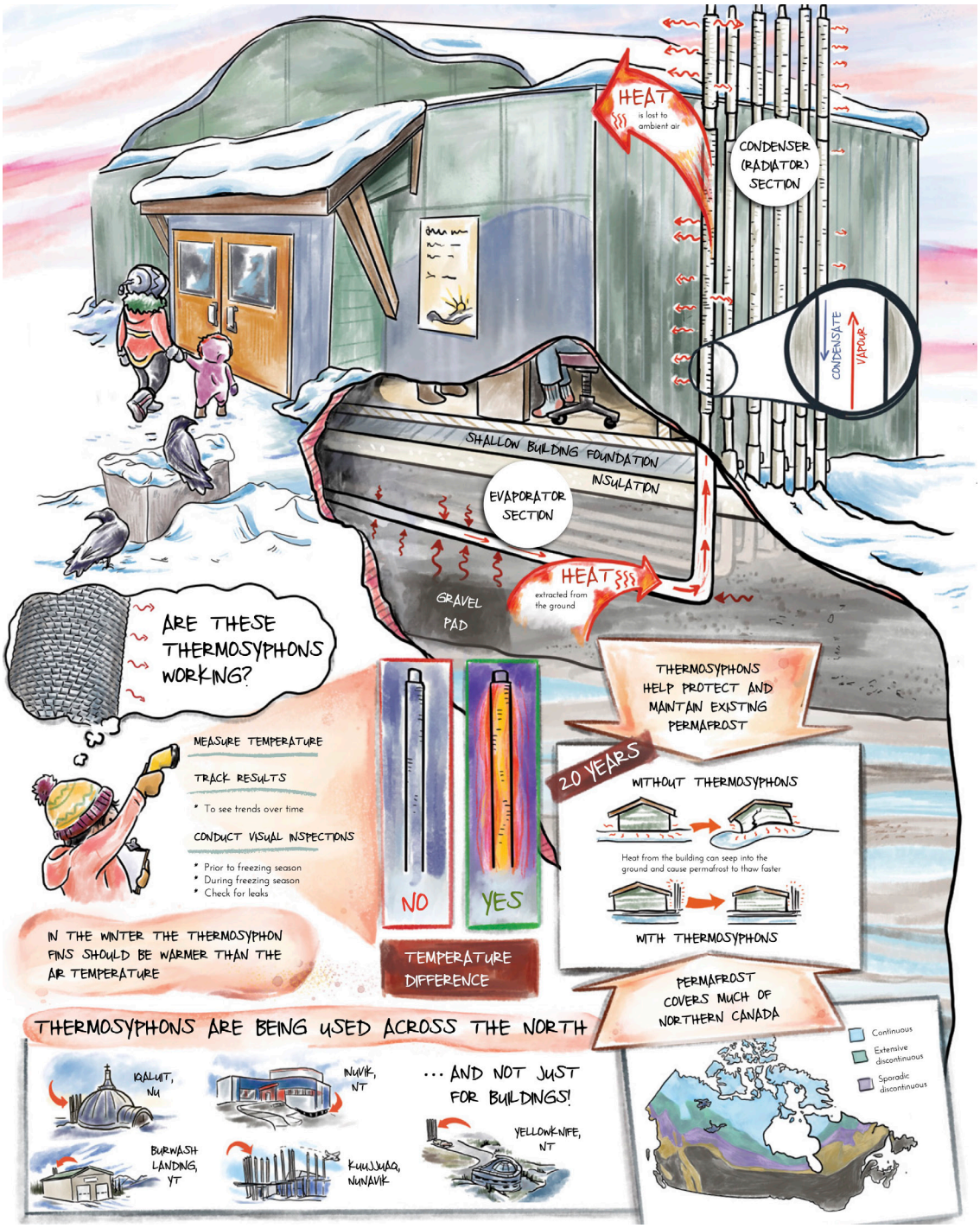


Figure 6.11: Infographic illustrating how thermosiphon foundation systems function, which ultimately aim to stop heat from a building from damaging the permafrost located beneath it. Source: Standards Council of Canada, 2020b.

Flooding is another common hazard in northern communities, which were often established adjacent to rivers and lakes in order to facilitate transportation. While overall seasonal and annual precipitation has increased—a trend projected to continue (*see* Changes in Temperature and Precipitation Across Canada chapter of Canada's Changing Climate Report)—trends and projections indicate decreased maximum snow water equivalent in much of the North (Mudryk et al., 2018). As a result, flood events resulting from high snowmelt runoff are declining in some large rivers. However, more intense precipitation may generate higher flow conditions in smaller rivers in the future, which would impact transportation infrastructure between communities. Many communities in northern Canada are also at risk of flooding from ice jams. These can occur in both winter and spring, and can cause extreme damage to communities and infrastructure along rivers, as well as impacting aquatic life (Beltaos, 2008). Extreme rainfall and rain-on-snow events may result in higher flows when ice is still present (Burn et al., 2016; Buttle et al., 2016), often leading to ice jams. In some cases, climate change has been associated with conditions leading to ice-jam flooding (Turcotte et al., 2019; Janowicz, 2017). In other cases, climate change has been linked to a possible reduction in the likelihood or severity of ice jams (Das et al., 2017; Burn et al., 2016). Given the complex processes leading to ice jam floods (e.g., Turcotte et al., 2019), local knowledge and Indigenous Knowledge, environmental monitoring and site-specific studies will improve understanding of how climate change is influencing the frequency and severity of ice-jam flooding.

One approach to reducing flood risk for northern communities involves the construction of engineered structures to reduce the amount of flood water to which an area is vulnerable (Burrell et al., 2015). The engineered dykes constructed in Dawson City, Yukon following a record flood event in May 1979 (Janowicz, 2010) are a good example of this; however, such initiatives are often reactionary responses. Moreover, inadequate designs (e.g., Beltaos and Doyle, 1996) or maintenance protocols may lead to a false impression of security. Beyond engineered structures, most flood reduction efforts are related to evaluating risks, like geohazard or flood mapping initiatives (Yukon Government, 2015), or integrating climate change modelling into flood hazard assessment (Beltaos, 2019; Lindenschmidt et al., 2016). These projects help communities understand risk to inform development, planning and emergency measures (Moudrak and Feltmate, 2017; Burrell et al., 2015), but may not address the risk itself. Clear documentation of how flood-related risks were accounted for is rarely available, with a lack of regulation and transparency regarding risk disclosure acting as barriers to implementation of flood risk management (Clark et al., 2022).

Risks of wildfire are projected to increase as a result of climate change (Erni et al., 2019; Kirchmeier-Young et al., 2017). FireSmart®—a process that involves thinning and brushing to reduce vegetation that could fuel fires in tree stands adjacent to residential areas—is a proven protective measure to limit the severity of fires in northern boreal forest systems (Schroeder, 2010). FireSmart® prescriptions have not yet been applied in all communities in the Northwest Territories and Yukon. Some northern communities are also investing in biomass harvesting as a means to manage and thin forests surrounding residential areas, while providing a source of energy for heating and developing new local economies (Yukon Government, 2016; Government of Northwest Territories, 2012).

6.5.5 Integrated planning for marine traffic

While increased ship traffic may bring economic benefits to Arctic regions (Christensen et al., 2018), community members across the Canadian Arctic have identified increased shipping as an area of concern that requires collaborative research and governance, including in the development of adaptation options to address both the direct (e.g., sea ice decline) and indirect (e.g., increased ship traffic) impacts of climate change on marine transportation (Dawson et al., 2020). Adaptation options include the development of infrastructure like safe harbours, navigational aids and their supporting systems, increased charting, and increased emergency response capacity and tools (related to search and rescue capabilities, as well as environmental impacts).

The development of low-impact corridors is emerging as a collaborative approach to moderating impacts and adapting travel through Canada's Arctic waters. Low-impact corridors, which can be developed using a co-management or collaborative approach, recognize areas of environmental and cultural significance by identifying voluntary maritime routes along which infrastructure, navigational support and emergency response services are clustered (Levitt, 2019), minimizing marine traffic in other areas. The use of local knowledge and Indigenous Knowledge to identify preferred corridors, areas to avoid, restrictions by season, modification of vessel operation and charting required provides an opportunity for meaningful inclusion of northern voices in the development of such corridors (Dawson et al., 2020) and represents an innovative approach to adaptation planning in a sector undergoing rapid change.

Other commercial interests, such as increased Arctic shipping and offshore oil and gas development, will also require co-management partners to develop innovative approaches for assessing and managing environmental risk (Arctic Monitoring and Assessment Programme, 2008; Inuit Circumpolar Council, 2008). Risk assessment methodologies will become important tools for understanding high-consequence, low-probability events, such as blow-outs and spills associated with offshore drilling and shipping (Arctic Council, 2009). These methodologies will be used to evaluate development scenarios and resolve differences among co-management partners. In addition, due to increasing traffic from growth in fisheries, tourism and heightened interest in exploration, there is a growing demand for search and rescue support in the Canadian Arctic, which puts stress on both human and financial resources (Clark et al., 2016b; Dawson et al., 2014; Arctic Monitoring and Assessment Programme, 2008).

6.6 Recognizing inherent capacity is key to building climate resilience

Organizations and individuals that recognize and embrace the inherent capacity of northern communities to adapt are key players in the pursuit of climate resilience.

Strong connections to the land, social structures that uphold community, and political environments that enable shared decision-making enhance existing resilience. While innovative research and decision-making partnerships signal a shift in leadership in northern Canada, the existing capacity of Indigenous Northerners based on millennia of observations and adaptation actions too often remains overlooked.

6.6.1 Describing northern capacity

In academic discussions, capacity can be understood in many ways, including as capability and competence (Howlett and Ramesh, 2016; Araral et al., 2015). The concept plays a substantial role in northern Canada, where the term "capacity" appears regularly in both popular media and political discourse. In the northern context, capacity discussions often focus on community, governance and the ability to adapt to climate change at the local scale (Darling et al., 2018; Simon, 2017; Graham, 2016; Irlbacher-Fox and Gibson, 2010), in addition to financial aspects. Other factors that impact capacity within communities include social justice issues, political mandates and institutional fragmentation (Ford and Furgal, 2009; Keskitalo, 2009; Bizikova et al., 2007).

The literature on capacity related to climate change focuses mainly on adaptive capacity—the ability of a community or group to adapt or adjust in light of changes to the environment (Ford et al., 2015; Engle, 2011; de Loë and Plummer, 2010). Vital components of adaptive capacity include the Indigenous Knowledge and local knowledge held by many northerners (Pearce et al., 2015), social structures that encourage resource sharing and mutual aid (Ayers and Forsyth, 2009), and a political landscape that encourages co-management (Armitage et al., 2011; Dale and Armitage, 2011). It is widely appreciated that Arctic communities have high rates of adaptive capacity and resilience (Ford et al., 2015; de Loë and Plummer, 2010). However, the ongoing impacts on Indigenous Peoples from colonization, including marginalization, power differentials in Canadian society and loss of land, negatively affect that capacity (Council of Canadian Academies, 2019; Ramos-Castillo et al 2017).

This context is also plagued by overarching questions related to colonialism, responsible conduct of research, lack of infrastructure, and conflicting mandates or priorities (Ford et al., 2015; Cameron, 2012; Glaas et al., 2010; Berkes and Jolly, 2001). The impacts of climate change, combined with the above-mentioned pressures, have the potential to affect adaptive capacity and adaptation success, especially among Indigenous populations (Council of Canadian Academies, 2019). The linkages between local and higher-level governance systems can facilitate or impede adaptation through the distribution of resources, including social services, resource rights and regulatory frameworks (Ford et al., 2015; Keskitalo, 2009; Smit and Wandel, 2006). There is also inadequate financial capacity to respond to climate change impacts

through adaptation actions, and this lack of capacity can limit adaptation options in northern Canada. For example, climate change poses further challenges to Canada's ability to fund, build and operate the country's infrastructure, especially in northern Canada (Clark et al., 2022).

In the North, increases in capacity can often be directly linked back to the work of small innovative groups and sometimes even to particular individuals. Increasingly, northern leaders are being invited to participate in the development of national standards like the Northern Infrastructure Standardization Initiative, convened by the Standards Council of Canada (*see* Section 6.5.1). Northern and Indigenous representation in major research initiatives, such as ArcticNet, PermafrostNet and the Canadian Mountain Network has also increased. Northern expertise is being directly sought and included in national policy research (e.g., Council of Canadian Academies, 2019; Crown-Indigenous Relations and Northern Affairs Canada, 2019; Environment and Climate Change Canada, 2016). Governments have recognized that northern representation and continued capacity investment in a wide range of social and economic areas is required to maintain and improve climate resilience (Crown-Indigenous Relations and Northern Affairs Canada, 2019).

6.6.2 Research

Innovative models for research collaboration are becoming increasingly prevalent across the North, as are calls challenging the scientific community to transform the way it conducts research and engages with Indigenous communities in a time of reconciliation (Wong et al., 2020). Indigenous organizations and governments are developing research strategies to ensure that research is governed, conducted, resourced and shared in ways aligning with Indigenous priorities and values. This includes, for example, the National Inuit Strategy on Research (Inuit Tapiriit Kanatami, 2018). At the same time, educational and research institutions across the North are growing their capacity to lead research activities and train the next generation of northern researchers. Northern institutions are playing a growing role in national research networks, changing approaches to funding, governance, partnerships, and training for research in the North. Importantly, these shifts are allowing Northerners to ask and answer research questions that are relevant to them, to build adaptive capacity and resilience, and to identify adaptation options (*see* Case Story 6.8).

Case Story 6.8: The Qaujigiartiit Health Research Centre

In Nunavut, the Qaujigiartiit Health Research Centre (QHRC) promotes the concept that research can be used as a tool for action—when one understands the scope and breadth of an issue, one is better-equipped to take action. The *Piliriqatigiinniq* Partnership Model for Community Health Research (ᐱᓕᕆᖅᑎᑦᓯᐊᖅᑎᓪᓗᒍ ᓄᓇᕗᑦ ᐊᑦᓂᐊᖅᓇᖅᑐᑦᑐᕆᔨᓂᖅᓴᓪᓗᑎᑦ ᖃᐅᔨᓴᖅᓯᖅ) was developed by the QHRC in the formative years of the Research Centre. It was created in response to a community-identified need for health research that explores topics of concern to Nunavummiut, the people who reside in Nunavut, and is collected, analyzed and disseminated in a holistic and collaborative way. The *Piliriqatigiinniq* Partnership Model is built upon the principle that anyone and everyone can be involved in health research in some capacity, because multi-disciplinary collaboration

strengthens research projects, provides added perspective to data analysis, and contributes to greater dissemination and implementation of findings across sectors.

The multi-disciplinary *Piliriqatigiinniq* Partnership Model contributes to building capacity in multiple sectors across Nunavut. It also reinforces the vision for health research that acknowledges the importance of both Western science models and Inuit *Qaujimajatuqangit* (Inuit traditional knowledge) in understanding and addressing health concerns of the Nunavummiut, contributes to the generation of meaningful knowledge, and ultimately supports progress towards improving the health of the Nunavummiut through research. The *Piliriqatigiinniq* Partnership Model is used as a guide for the development of each health research project implemented at the QHRC. This model is a reminder to look beyond the scope of what is defined as "health" and "research" to include knowledge holders and stakeholders from other disciplines and walks of life.

For more information, see Qaujigiartiit Health Research Centre (2019).

The Inuit Health Survey is a powerful example of research designed and led by Northerners that enhances health research capacity among Inuit and contributes to improved well-being. First conducted during the International Polar Year in 2007–2008 and led by McGill University (Centre for Indigenous Peoples' Nutrition and Environment, n.d.), the survey was groundbreaking as it generated Inuit-specific health data that had not previously been gathered on such a scale. Since the implementation of that survey, Inuit organizations have been promoting the significance of thorough and regionally specific data for understanding Inuit health and for making evidence-based decisions, while at the same time advancing Inuit self-determination in research.

In 2018, ITK announced the creation of the *Qanuippitaa?* National Inuit Health Survey (QNIHS) (Inuit Tapiriit Kanatami, n.d.). QNIHS is the first national health survey led by Inuit, with the objective of providing high quality, Inuit-determined and Inuit-owned data to monitor change, identify strengths and gaps, and inform decision making, leading to improved health and wellness among Inuit in Canada. The regional Inuit organizations are developing and implementing the QNIHS in Nunatsiavut, Nunavik, Nunavut and the Inuvialuit Settlement Region, in collaboration with ITK. Governance structures are being created within each region to ensure that all aspects of the survey are constructed with the input and priorities of Inuit individuals, families and communities from across Inuit Nunangat. The QNIHS will also include an urban component, implemented in partnership with organizations mandated to provide services for urban Inuit populations. An urban Inuit survey will take place in Ottawa for the first survey cycle and may be expanded to other urban centres in subsequent cycles.

As the QNIHS is Inuit-led, it uses a holistic health framework that is inclusive of physical, emotional and mental wellness; environmental health; and Inuit social determinants of health. These important and diverse health and well-being indicators will be monitored every five years (Inuit Tapiriit Kanatami, n.d.). Collecting Inuit-owned health data on an ongoing basis and in a way that is designed by, and appropriate for, Inuit will provide regional governments and organizations with evidence to inform policy and programming decisions. Importantly, a major focus of the design of the program is creating innovative training and capacity enhancement approaches, to ensure that the QNIHS process enhances health research capacity across Inuit Nunangat (Inuit Tapiriit Kanatami, n.d.).

Citizen science is also an emerging pathway to advance collaborative approaches to adaptation and policy development (Kythreotis et al., 2019). Citizen science elevates the role of individuals and community members in such a way that local knowledge and Indigenous Knowledge can be more directly applied in identifying and implementing solutions. Examples include the wildlife observations project of the Dan Keyi Renewable Resources Council (Dän Keyi Renewable Resources Council, 2019) and SIKU, the Indigenous Knowledge Social Network (Arctic Eider Society, 2019). Distinguishing impacts caused by climate change and other forms of human and natural disturbance allows for better prediction of what parts of a landscape or ecosystem are most likely to shift under current and anticipated future environmental changes (Folke et al., 2004).

In recognition of the linkages between Indigenous self-determination, community health and resilience, and citizen concern over climate and environmental change, research networks and funding bodies have been modernizing their structures to provide greater opportunities for community-based research. In the fall of 2018, the Social Sciences and Humanities Research Council of Canada held a special call for Indigenous Research Capacity and Reconciliation Connection Grants (Social Sciences and Humanities Research Council, 2018). Indigenous organizations were eligible award holders, to apply and manage research funds awarded under the program. ArcticNet, a research network that studies the impacts of climate change in the Canadian Arctic, has devoted funding to a North by North program and invested in research coordination capacity through northern and Inuit organizations in each of the territories, as well as in Nunatsiavut and Nunavik (Reedman, 2020). North by North is also awarding research funds directly to communities. These initiatives have opened the door for more in-depth consideration about who the key actors are in northern research and what role they can play in contemporary research collaboration (*see* Case Story 6.9). They have established greater connections between research and action, improved research coordination and engaged diverse stakeholders in identifying solutions for addressing fundamental issues of community resilience (Canadian Mountain Network Yukon Initiating Group, 2017).

Case Story 6.9: *Ikaarvik*: Barriers to Bridges

Ikaarvik is the Inuktitut word for bridge and the intention of the Barriers to Bridges program that *Ikaarvik* operates. *Ikaarvik* aims to build bridges between research communities and northern communities by promoting youth involvement in research. *Ikaarvik* gives youth the opportunities, confidence, and experience to explore how Inuit Knowledge and science can be combined to address northern issues. The program empowers youth to work with their communities in identifying local research priorities and to build relationships with researchers, government, and industry to address those priorities. By focusing on youth, *Ikaarvik* is ensuring that future Inuit leaders will be familiar and comfortable with both Inuit Knowledge and scientific research processes, thus enabling Inuit to have a strong voice in determining research priorities in their communities across the North.

Video 6.1: Ikaarvik: Barriers to Bridges is a program that works with Arctic youth to bridge between research and their communities. Source: Ocean Wise, 2019. https://www.youtube.com/watch?v=cVXGM6hkbRY

6.6.3 Northern development and resilience

While much of the dialogue around climate change impacts and adaptation focuses on limiting the impacts of undesirable changes on the environment, society and culture, climate change impacts also present new economic opportunities. Northern development, in part facilitated by climate change through impacts such as longer ice-free seasons and the appearance of new commercially viable harvest species, may bring socioeconomic benefits to the North. However, there are concerns about how these benefits are distributed and whether local communities are positively impacted (Ford and Furgal, 2009). Such economic growth has potential to impact society and culture in ways that are often difficult to assess, anticipate and disentangle from concurrent change.

While there is potential for increased economic activity and Arctic shipping, made possible from longer ice free season, there are associated environmental risks (*see* International Dimensions chapter of the National Issues Report; Arctic Council, 2009). Increased access to mining is providing economic opportunities, but is also associated with remediation concerns evidenced by a long history of abandoned mines in the North (Sandlos and Keeling, 2016; Caine and Krogman, 2010). Extractive industries also tend to experience boom and bust periods. Increased drug and alcohol abuse, housing problems and transiency are often associated with the boom part of the cycle, while out-migration and poverty are often associated with the bust (Southcott, 2015).

With respect to Arctic fisheries, increases in some fish stocks and improved access due to a longer open-water season are leading to interest in commercializing fisheries that either did not exist in the past or were

limited to subsistence use. The appearance of new fish species in Arctic waters, such as sockeye salmon in the Beaufort Sea (Niemi et al., 2019; Irvine et al., 2009; Babaluk et al., 2000) will also lead to new demands for commercial fishing. In response to growth in Arctic fisheries, co-management partners will need to establish sustainable harvest levels for these stocks in Arctic waters, especially for newly arrived species and where historical data are limited (Staples, 2013). Commercial harvesting is also adding stress on fish and wildlife that are directly and indirectly impacted by climate change (Government of Canada, 2019b).

Some regions in the North are identifying strategies that consider economic benefit, resilience and adaptation while integrating cultural values, Indigenous livelihoods and local modern economies. The Nunatsiavut Government's Department of Education and Economic Development Division runs a char fishery social enterprise whereby Inuit fishers are allocated licenses by the Nunatsiavut Government and all the fish is landed and processed at the fish plant in Nain. Every year, the Division provides a financial contribution to the Torngat Fish Producers Co-operative, a local Indigenous-led business, to purchase between 10,000 and 15,000 pounds of processed Arctic char, which is then distributed to communities through the community freezer programs (Torngat Fish Producers Cooperative, 2022). In addition to contributing to food security, this program supports the local fishery and processing enterprise, providing employment to local fishers and plant workers in their home communities. Notably, the community freezer programs also trade a portion of their char for cod from NunatuKavut Community Council, contributing to diet diversity and building regional economic collaborations.

It is not easy to prevent the negative impacts on northern communities that are inevitably associated with the socioeconomic opportunities resulting from climate change. However, it is possible to build sustainable resource industries in ways that benefit local communities and also provide the resources needed to build social resiliency and health and well-being (Southcott, 2015). Modern treaties, self-government, devolution and co-management, rigorous environmental and socioeconomic assessments and regulations, as well as corporate responsibility are, and will continue to be, crucial requirements for advancing resiliency (Southcott, 2015).

6.7 Moving forward

While much is being done in northern Canada to adapt to our changing climate, there is a continued need to understand the prevalence, rate and magnitude of climate change impacts on both our natural environment and our society to enable responsive adaptation action. Some of the emerging issues identified below warrant additional research or identify gaps in policy or adaptation responses that impair resilience. They also present opportunities for leadership in a thriving North.

While the key messages in this chapter are broad in nature, there are several common themes related to gaps in knowledge and emerging issues. These include: data availability; building resilience to multiple stressors; recognition of health, well-being and societal impacts; responsive decision making and co-governance; placing value on Indigenous Knowledge and inherent capacity; and understanding limits to adaptation.

6.7.1 Lack of data

In virtually every topic covered in this chapter, a lack of data hampers our understanding of existing climate change impacts, which in turn limits or influences the nature and effectiveness of adaptation action. Data to support understanding of how human systems and the biophysical environment are responding to climate change is lacking—for example, how new migrant species will interact with existing resident species, or how native species will vary their responses to climate change impacts. Cascading changes, feedbacks and new types of disturbances are emerging, but rarely is there sufficient data to understand these changes or to project them in advance.

Integrative approaches that consider Western and Indigenous Knowledge help to expand what is regarded as "data." Many observations and solutions are already present in ways that governments and decision-makers have historically not appreciated or acted upon. Holistic understanding improves in locations where collaboration between Indigenous Knowledge holders and scientists has been successful. However, there are still large areas, such as non-coastal areas of the Arctic Ocean where both Indigenous Knowledge and Western scientific approaches are unable to provide complete understanding of natural systems and how they are changing (Niemi, 2019).

In many community settings, signs of climate change impacts can be missed. For example, the frequency of grading of a gravel road over degrading permafrost or the number of times a house on such permafrost is levelled can give important information of how permafrost thaw is impacting a community. Likewise, climate change-related impacts on travel safety are rarely documented in ways that can be used to support adaptation action or even comprehensive assessments of the scope of the issue. Details regarding delayed flights or the number of local search and rescue operations due to unusual weather or ice conditions, for example, are rarely captured beyond anecdotal evidence; also, in cases where records are kept locally, they have yet to be examined across northern Canada (The Standing Senate Committee on Fisheries and Oceans, 2018; Clark et al., 2016b). Developing tools, approaches and capacity to support the added effort to document and share this information as "data" for subsequent analysis could help address the issues related to a lack of data, but this will take significant and sustained effort.

6.7.2 Building resilience to multiple stressors

The impacts of climate change on the biophysical environment are often strongly influenced by non-climate-related pressures, including those resulting from northern development, changing demographics, long-range transport of chemicals and pollutants, and a diverse range of other impacts on the environment. It is recognized that measures that build resilience are necessary regardless of whether climate change is the dominant cause of disturbance or only one contributor. Changes to the biophysical environment are not limited to the Arctic, and investigating impacts of northern environmental changes on other regions of the world (e.g., the relationship between Arctic sea ice loss and mid-latitude weather) is emerging as an important issue of study (IPCC, 2019).

Communities are regularly taking action to build resilience, both in response to the impacts of climate change and in response to other, non-climate-related stressors. This is done even in the absence of quantitative data regarding projected changes (Meredith et al., 2019). Reflection on lived experience and reliance on the dominant

knowledge system of the community are heavily used in most local- and regional-level decisions. Northern communities often make projections based on their understanding of changes that have already occurred and on what make them resilient. Instead of asking why a change is occurring, they are focused on taking tangible actions that will create base levels of resilience. For example, trail projects help maintain access to harvest sites and are often completed without fully examining whether a newly built or reconstructed trail will remain resilient to future conditions. The immediate benefits of rebuilding a trail can improve resilience in the short term even if further adaptation is needed later (Pearce et al., 2015). Meanwhile, improvements to housing, social programming, education, community infrastructure and the reinvigoration of cultural practices improve resilience regardless of what outside forces are impacting them. There is an important need to research, fund and support mechanisms for social resilience.

6.7.3 Recognition of health, well-being and societal impacts of climate change

There is a growing body of literature, much of it created in partnership with northern communities and individuals, identifying ecological grief as an emerging mental health issue (e.g., Cunsolo et al., 2020; Cunsolo and Ellis, 2018). Recognition of compounding mental health concerns, including those associated with ecological grief, is leading to a call to address broader socioeconomic determinants of mental health through increased care and support, both within and outside of the healthcare system.

Concerns associated with physical human health impacts resulting from climate change, or perceived to be associated with climate change, are also growing. This includes concerns related to contaminant exposure (e.g., through the consumption of wild foods that, in turn, are exposed to contaminants as a result of thawing permafrost), food insecurity and health impacts of wildfire smoke (Rautio et al., 2020, Creed et al., 2018, Dodd et al., 2018). There is also increasing recognition of the impacts of northern development on mental, physical, and emotional health and well-being in communities. For example, close to 50 Indigenous communities in Northwest Territories are downstream of oilsands production in Alberta (McCreadie, 2014). There are broad calls for continued work to understand these impacts and the ways that they are compounded by climate change, and to carefully examine the costs and benefits of development on community health and social resilience (Assembly of First Nations, 2019; Inuit Tapiriit Kanatami 2019a). In recognition of the urgency of work to address Arctic health and well-being in the face of climate change impacts, the Lancet medical journal has convened the Lancet Commission on Arctic Health (Adams et al., 2019). Findings from the Lancet Commission are expected in 2022.

6.7.4 Need for responsive decision making and co-governance

There are growing calls for cautious and careful exploration of the costs and benefits related to emerging opportunities and their potential impacts on northern societies and cultures. Citizen science is evolving as an approach to advancing collaborative approaches to climate change adaptation, and co-management boards are proving themselves to be effective in responsive, collaborative decision making (*see* Section 6.5.2). However, northern development is testing the capacity of co-management boards and communities, while the

ability to channel Indigenous Knowledge, environmental monitoring and environmental change information to those boards for integration into management decisions is becoming increasingly important in the pursuit of equity among the rights-holders involved in decision making (Arngna'naaq et al., 2020). Continued work is warranted to ensure that Indigenous Knowledge and Western knowledge are both drawn upon to inform responsive co-management decisions, and pathways to ensure that this happens effectively must be developed, tested, implemented and shared across the North. In addition, climate change impacts cannot be viewed in isolation from other stressors, but there is no trusted body with a mandate to review, understand, and recommend actions to address cumulative impacts. Efforts to understand cumulative impacts can become polarizing when they do not fit well within existing planning or environmental review processes (*see* Section 6.5.2; Blakley and Franks, 2021).

Meanwhile, new northern leadership in research is shifting and refocusing the research questions that are being posed and investigated; this in turn is creating opportunities for new forms of collaborative research, including Indigenous-led research following Indigenous research methodologies. Establishing greater connections between research and action, improving research coordination within and outside of Canada's North, and engaging diverse stakeholders and rights-holders in identifying solutions for addressing fundamental issues of community resilience and adaptation are all pressing issues in northern Canada.

6.7.5 Recognition of Indigenous Knowledge and inherent capacity

With an increasing reliance on co-management boards and decision-making tables, there is increasing need to value both Indigenous Knowledge and knowledge from land users in informing responsive co-management practices. Future adaptation initiatives will continue to be enhanced through co-learning, cooperation and the implementation of co-management recommendations and decisions (Abram et al., 2019).

There are growing calls to stop seeking "validation" of Indigenous Knowledge using Western science approaches, but rather to recognize Indigenous Knowledge as a distinct and equally valued knowledge system. Northerners are expressing concerns about adequate recognition of Indigenous Knowledge in evidence-based policy making and decision making, and are voicing a continued call for the inclusion of Indigenous Knowledge holders and other Northerners in national policy dialogues. There is a desire to see the inherent capacity present in Northerners, especially Indigenous Northerners, as a key tool in climate change adaptation and sustained northern resilience (Copper Jack et al., 2020).

6.7.6 Understanding the limits of adaptation

While most of the adaptation and resilience work in the North is carried out with the goal of maintaining and improving quality of life, the magnitude, spatial extent and pace of change will create conditions where, in some cases, there are no economically or socially viable adaptation solutions. This is particularly true under a high emissions future (RCP 8.5; IPCC, 2019). Even in cases where a technological solution such as reinforcement of infrastructure may provide protection, the spatial extent of the impacts, coupled with the small population and limited scale of economic activity in the North, limit the likelihood that such a solution could be implemented (Council of Yukon First Nations and Assembly of First Nations, 2019, Inuit Tapiriit

Kanatami, 2019a). In addition, cultural connections to place are very strong in most Northern communities; this means that a solution considered appropriate in other locations, like relocation following a climate-related disaster, may be unacceptable in a Northern context.

Even in places where drastic action such as relocation is being undertaken (Moses, 2018), Northern conversations of the "acceptability of policy or system change" (IPCC, 2018) are deeply intertwined with the issues of reconciliation and equity, and the resolution of social justice issues. Exploring the acceptability of topics such as planned relocation requires time, empathetic dialogue, and a commitment to respectful exploration of many options before decisions are finalized (Arngna'naaq et al., 2020; Inuit Tapiriit Kanatami 2018). There is no "step by step" approach for how to advance consideration of topics that society considers unacceptable now. Despite a growing need for sensitive but realistic exploration of the limits to which maintaining and improving current practice is sustainable, past practices by researchers and governments can act as a barrier to taking urgent action. Many Indigenous leaders and organizations are providing guidance that can help facilitate reconciliation and support collaborative work to initiate what promise to be important but very challenging conversations (e.g., Wong et al., 2020, Inuit Tapiriit Kanatami, 2019a, McGregor, 2018).

6.8 Conclusion

The 2019 report of an expert panel convened by the Council of Canadian Academies recognized climate risks to northern communities, as well as risks to Indigenous ways of life, as among the top climate risks facing Canada. The panel recognized "the centrality of Arctic issues and sovereignty to national and international affairs, [elevating] the risks to Arctic areas to the national level" (Council of Canadian Academies, 2019). Addressing climate change risks and impacts through adaptation is important to more than just the northern communities themselves. Northern leadership and innovation will help to maintain resilience, while also serving the interests of Canada's Arctic sovereignty and identity. Successful adaptation in the North will help Canada demonstrate leadership among Arctic nations.

As recognition of the broad significance of adaptation to climate change in northern Canada is growing across the country, the conversation around northern adaptation is shifting from a focus on biophysical impacts to one that examines complex issues such as mental health, socioeconomic equity and the inherent right to practice traditional ways of life. Climate change impacts are felt in almost every aspect of northern environments and populations, and often amplify existing socioeconomic issues present in Canada's North. While there is an absence of economic analysis on the direct and indirect costs of climate change impacts and adaptation in the region, it is clear that costs will be substantial and cannot be borne by Northerners alone. Questions around who will bear those costs, and how, remain.

While adaptation actions like those profiled in this chapter are underway across Canada's North, and are in many cases being led by northern governments and communities, there is a growing sense that the rate of change in northern Canada is outpacing the capacity to adapt. Permanent changes to parts of the

northern environment are either occurring or expected to occur, and these have irreversible impacts on the generations-long ability of people to support themselves from the land, and ways that people interact with the land, and practice traditional and chosen ways of life. The Indigenous Peoples of the North have already endured over a century of cultural disruption and will not simply abandon traditional practices and values. While climate change impacts reach beyond many previously experienced conditions, trust in traditional teachings is providing sources of resilience that are not well represented in Western knowledge systems.

In much of the discourse about adaptation in Canada, there is an expression of the urgent need to act and not to allow insufficient data or uncertainty regarding the nature or magnitude of impacts to delay that action. However, there is an absence in this discourse about the limits of adaptation and a lack of recognition of how to identify situations in which it may not be possible to adapt. Permanent change to the migration pattern of a species that has been relied upon for millennia, or continued infrastructure damage to a community caused by permafrost thaw may not be solvable through adaptation action—instead, a new way of being in the absence of that traditional food or a relocation of key community infrastructure may be warranted. In the discourse about climate change impacts in northern Canada, the limits of adaptation are often neglected, as is the timing of when to begin exploring the need for a new way of being. It is time for these conversations to begin.

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