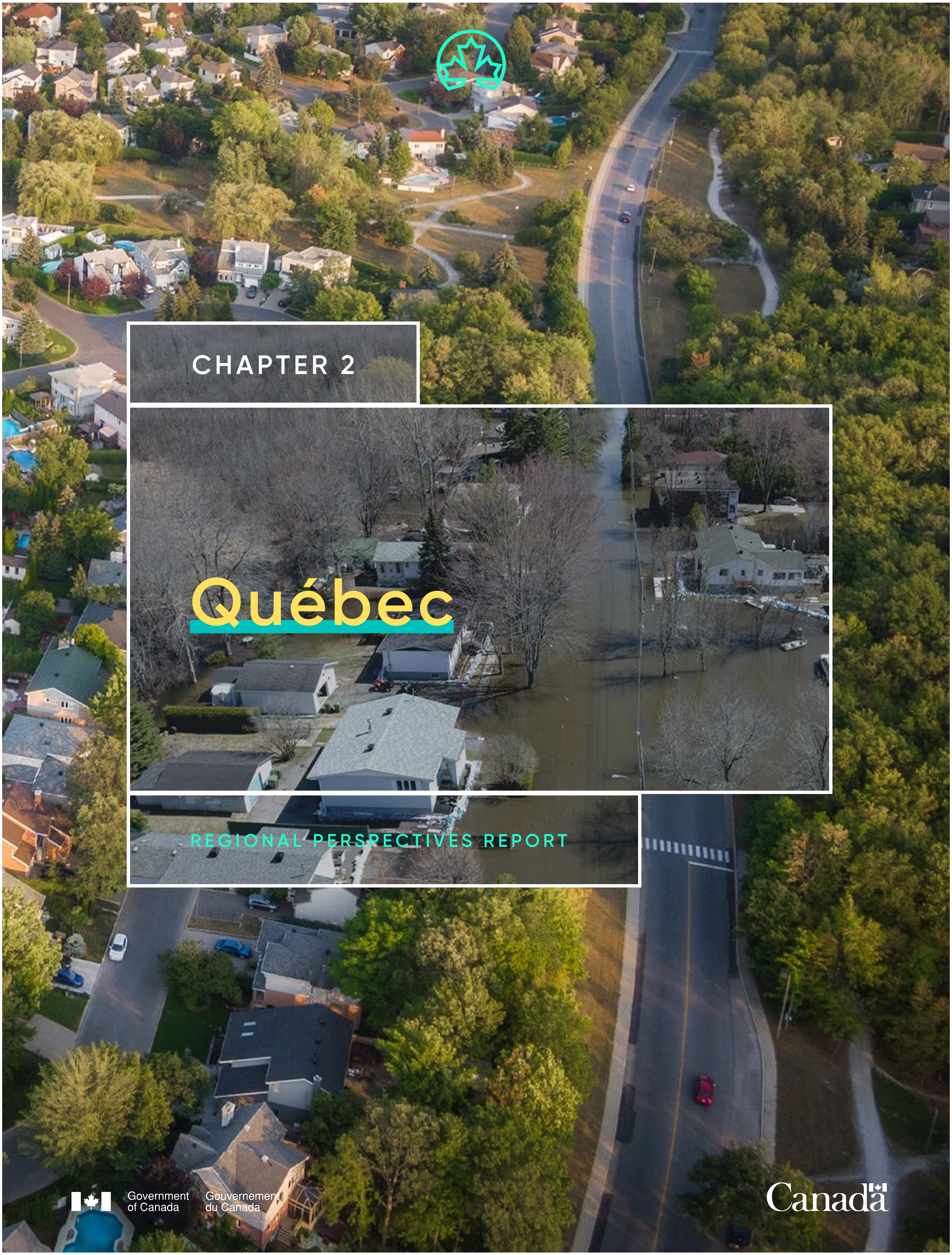

CHAPTER 2

Québec

REGIONAL PERSPECTIVES REPORT

Government of Canada / Gouvernement du Canada

Canada

Coordinating lead author

Angelica Alberti-Dufort, M. Eng., Ouranos

Lead authors

Valérie Bourduas Crouhen, Caisse de dépôt et placement du Québec (previously with Ouranos)

David Demers-Bouffard, Institut national de santé publique du Québec

Rebecca Hennigs, Littoral Research Chair, Université Laval (previously with Ouranos)

Simon Legault, Institut de recherche et de développement en agroenvironnement (previously with Ouranos)

Julie Cunningham, Ph.D., Institut national de santé publique du Québec (previously with Ouranos)

Under the direction of Caroline Larrivée, Ouranos

Contributing authors

Hélène Côté (Ouranos)

Pierre Gosselin, M.D. (Institut national de santé publique du Québec)

Nathalie Bleau (Ouranos)

Chantal Quintin (Ouranos)

Richard Turcotte, Ph.D. (Ministère de l'Environnement et de la Lutte contre les changements climatiques)

Alexandrine Bisaillon (Ouranos)

Robert Siron, Ph.D. (Ouranos)

Anne Blondlot (Ouranos)

Jacinthe Clavet-Gaumont (Hydro-Québec)

Daniel Houle, Ph.D. (Université du Québec à Montréal)

Émilie Bresson, Ph.D. (Ouranos)

Stéphanie Bleau (Ouranos)

Recommended citation

Alberti-Dufort, A., Bourduas Crouhen, V., Demers-Bouffard, D., Hennigs, R., Legault, S., Cunningham, J., Larrivée, C. and Ouranos (2022). Quebec; Chapter 2 *in* Canada in a Changing Climate: Regional Perspectives Report, (ed.) F.J. Warren, N. Lulham, D.L. Dupuis, and D.S. Lemmen; Government of Canada, Ottawa, Ontario.

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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.

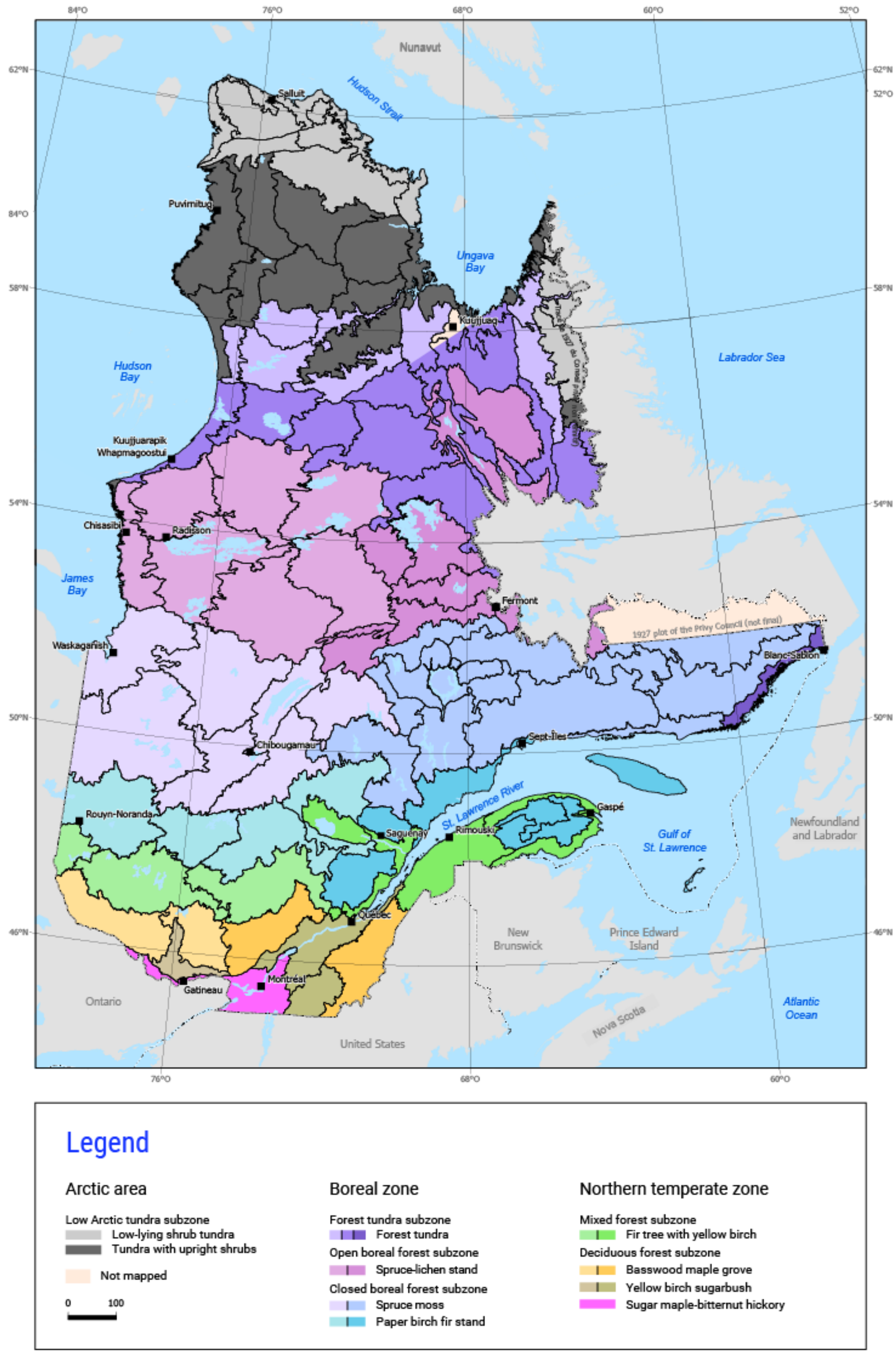


Figure 2.1: Vegetation zones, bioclimatic domains and ecological regions of Quebec. Source: Ministère des Forêts, de la Faune et des Parcs du Québec, 2021.

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).

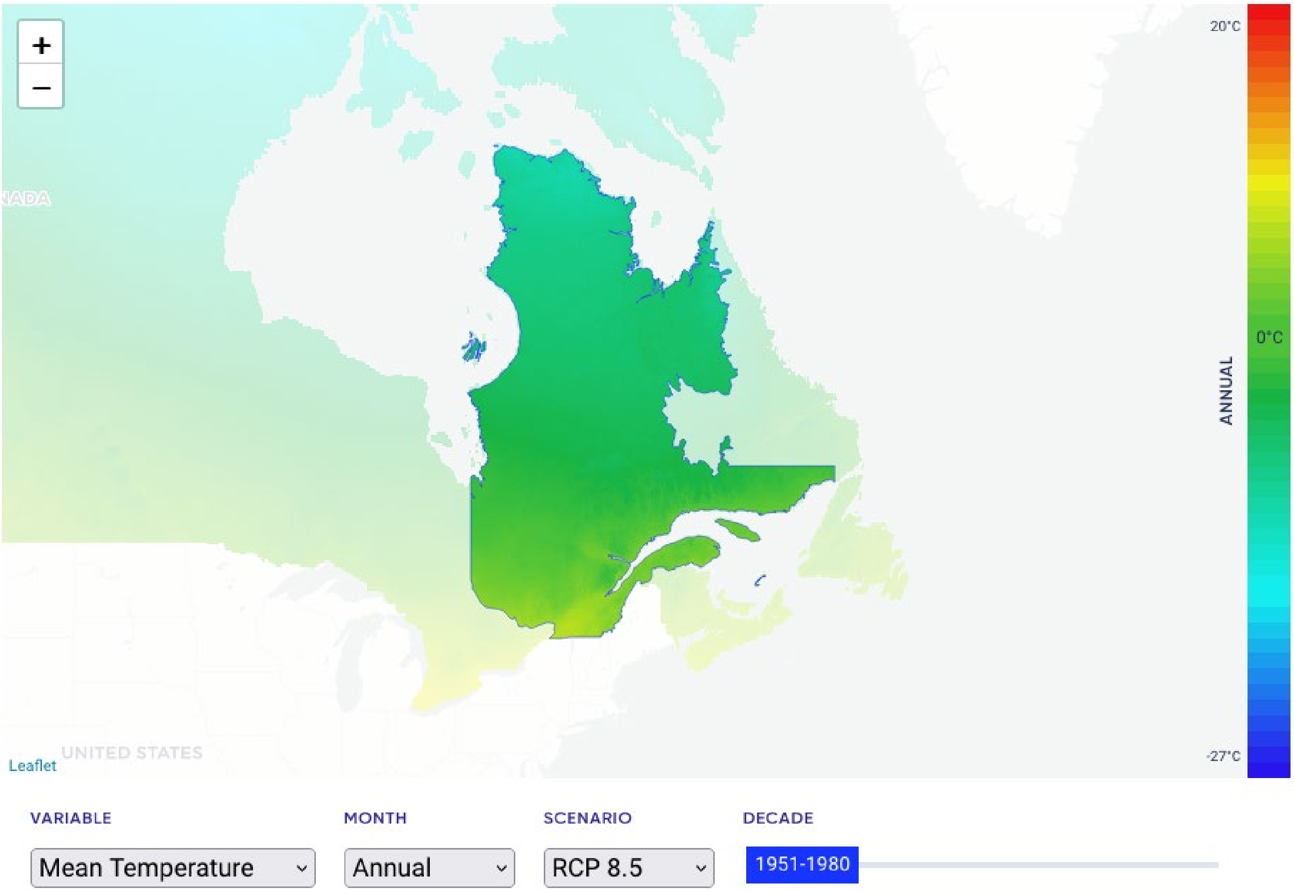


Figure 2.2: Interactive regional map of Quebec (adapted from the climatedata.ca portal) which provides information on various climate variables from 1980 to 2100 based on the high emission scenario (RCP8.5). Source: climatedata.ca

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).

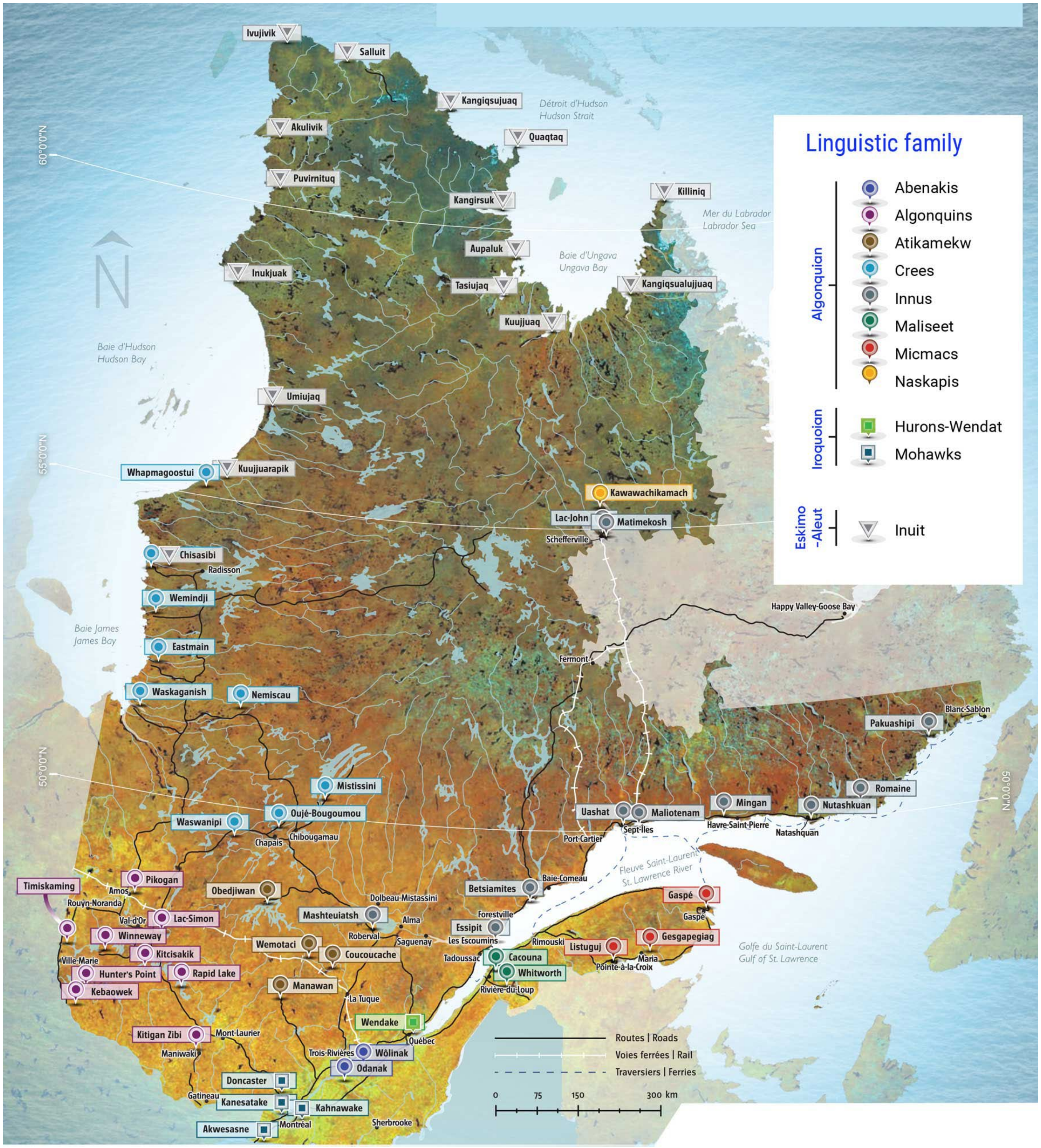


Figure 2.3: Map of the 11 Indigenous nations in Quebec. Source: Indigenous Services Canada, 2020

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.

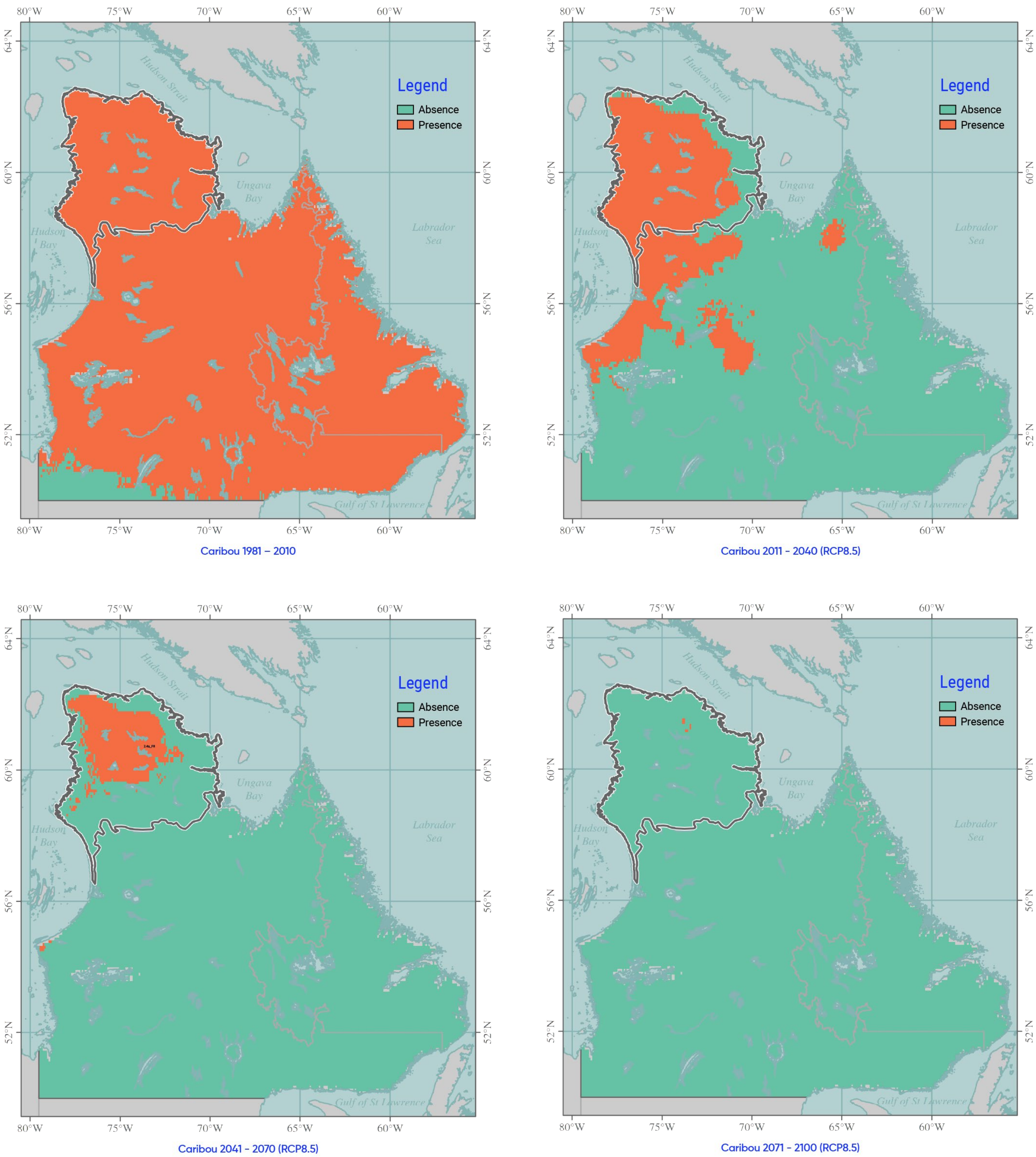


Figure 2.4: Reduction in range and numbers of migratory caribou. Source: Berteaux et al., 2018b – The Tundra Nunavik Project.

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.

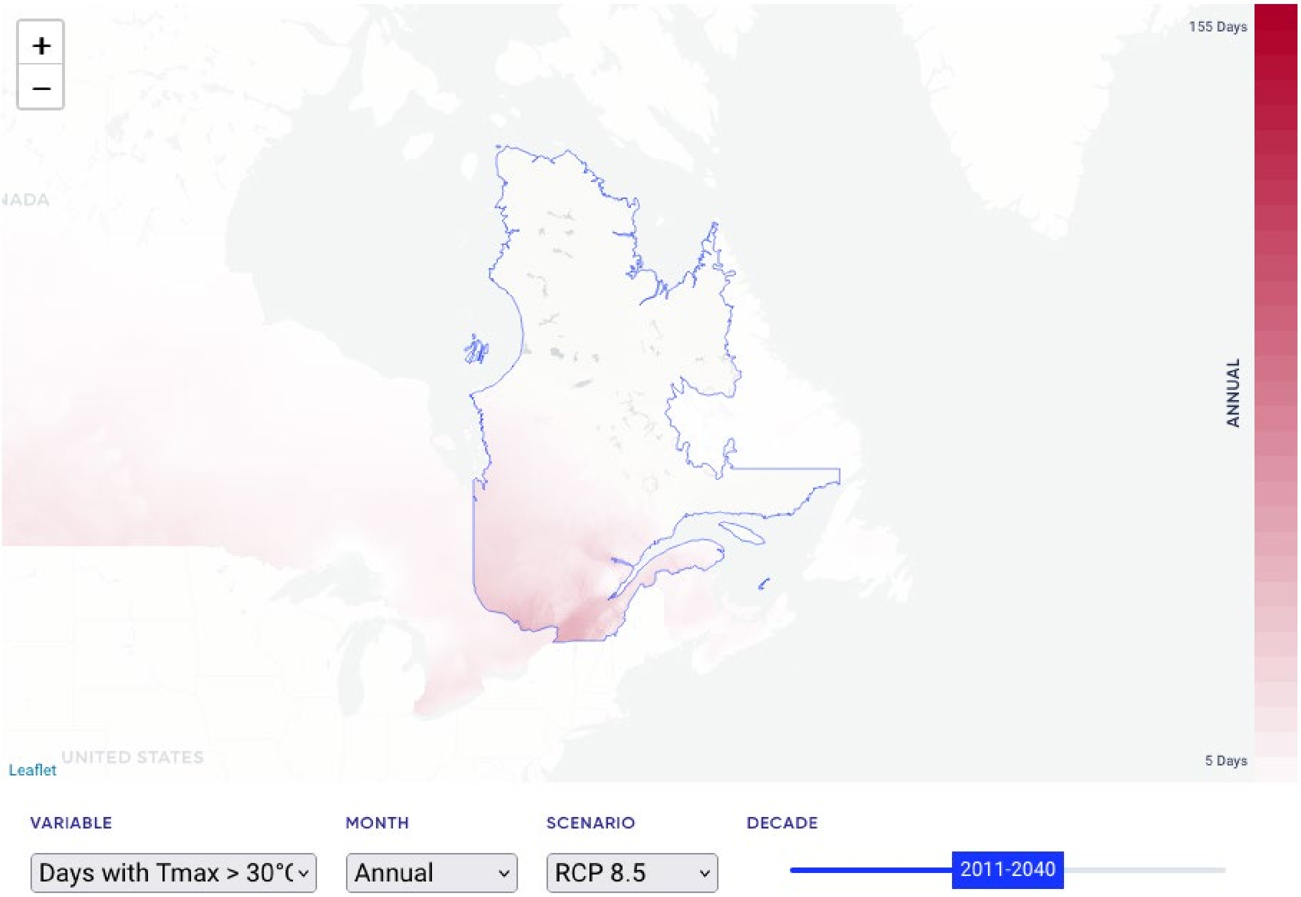
In Quebec's urban areas, populations face significant heat waves, and heavy rainfall events can overload sewage and stormwater management systems, in addition to causing wastewater overflows into the environment. Furthermore, urban sprawl is increasing and several practices that are associated with development, 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).

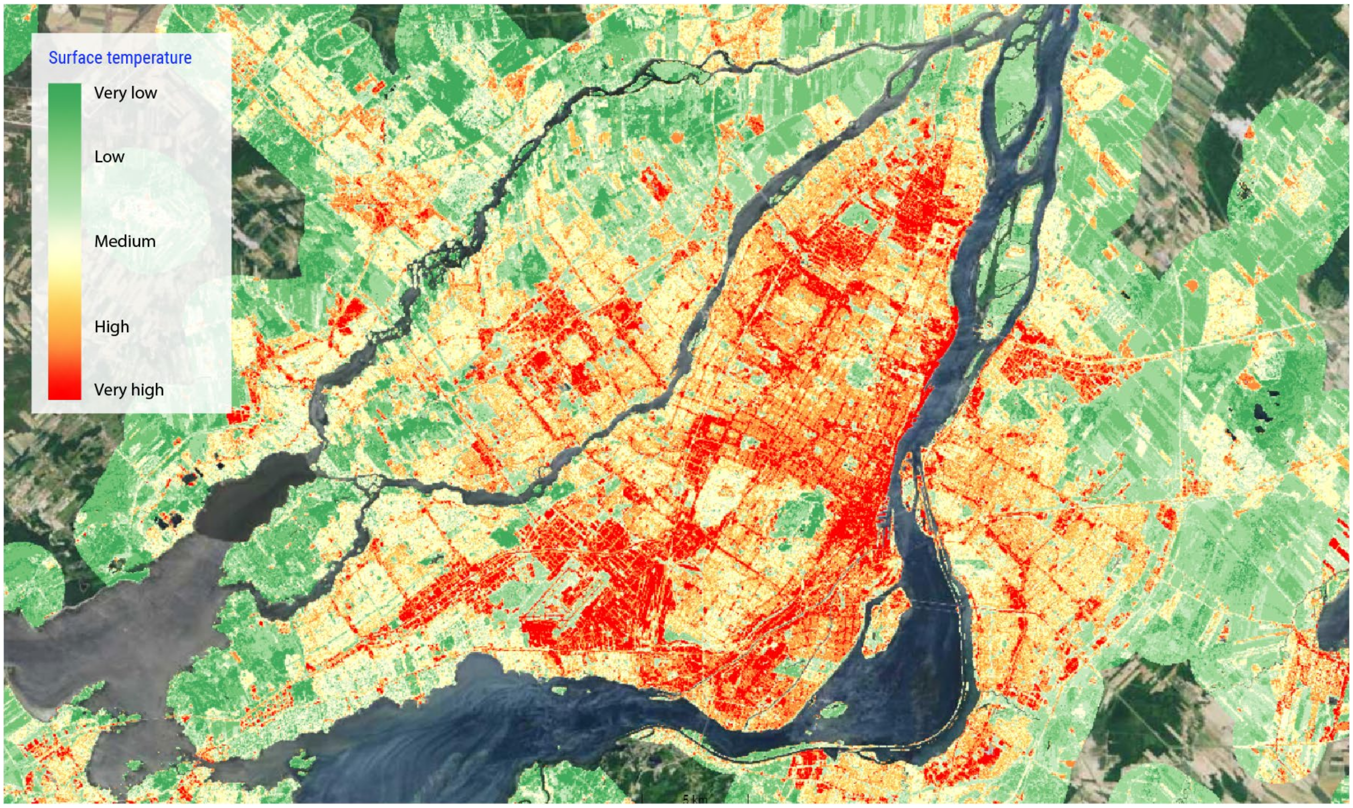


Figure 2.5: Map of heat islands in Montreal, Quebec. Source: Ministère de la Sécurité publique du Québec, 2018a.

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).

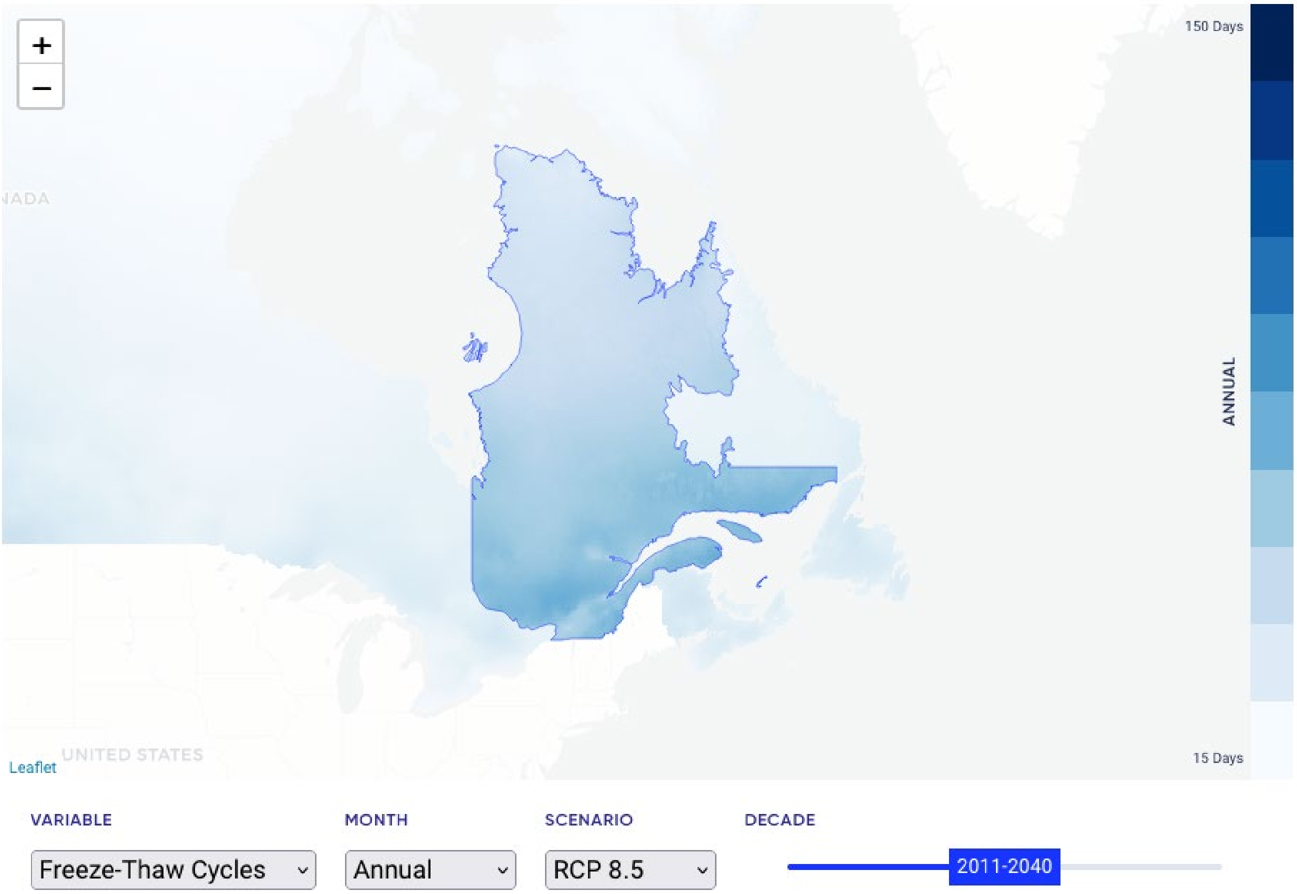
In recent decades, urban sprawl has resulted in a significant expansion in the area covered by impervious surfaces, thereby increasing stormwater runoff (Thomas and Da Cunha, 2017). Most cities still have sewer lines in their older areas that carry both stormwater and wastewater. For Quebec as a whole, 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.

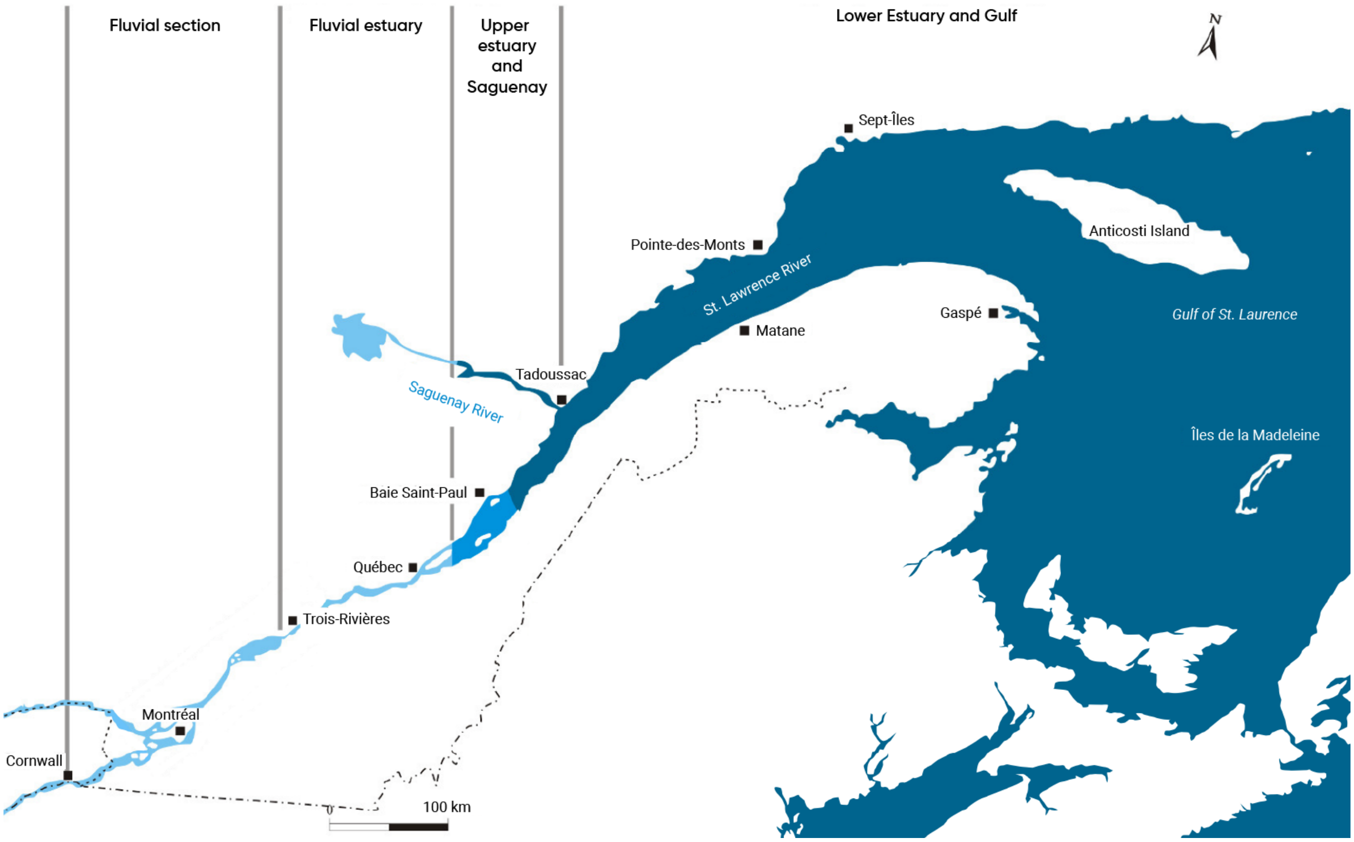


Figure 2.7: Fluvial section, Estuary and Gulf of St. Lawrence. Source: St. Lawrence Action Plan, n.d.

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).

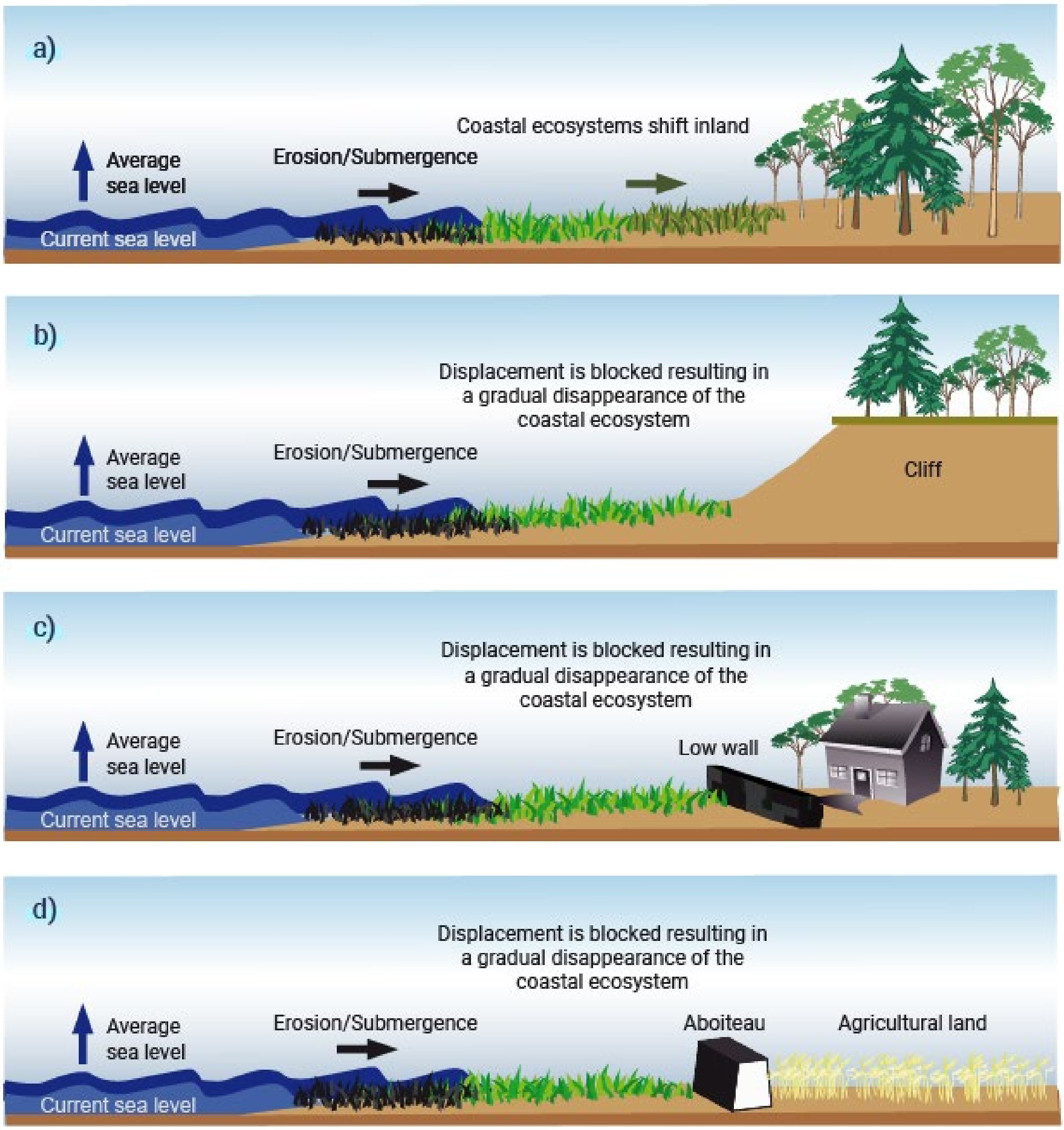


Figure 2.9: Diagram showing the factors that influence coastal squeeze. Source: Bernatchez and Quintin, 2016.

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

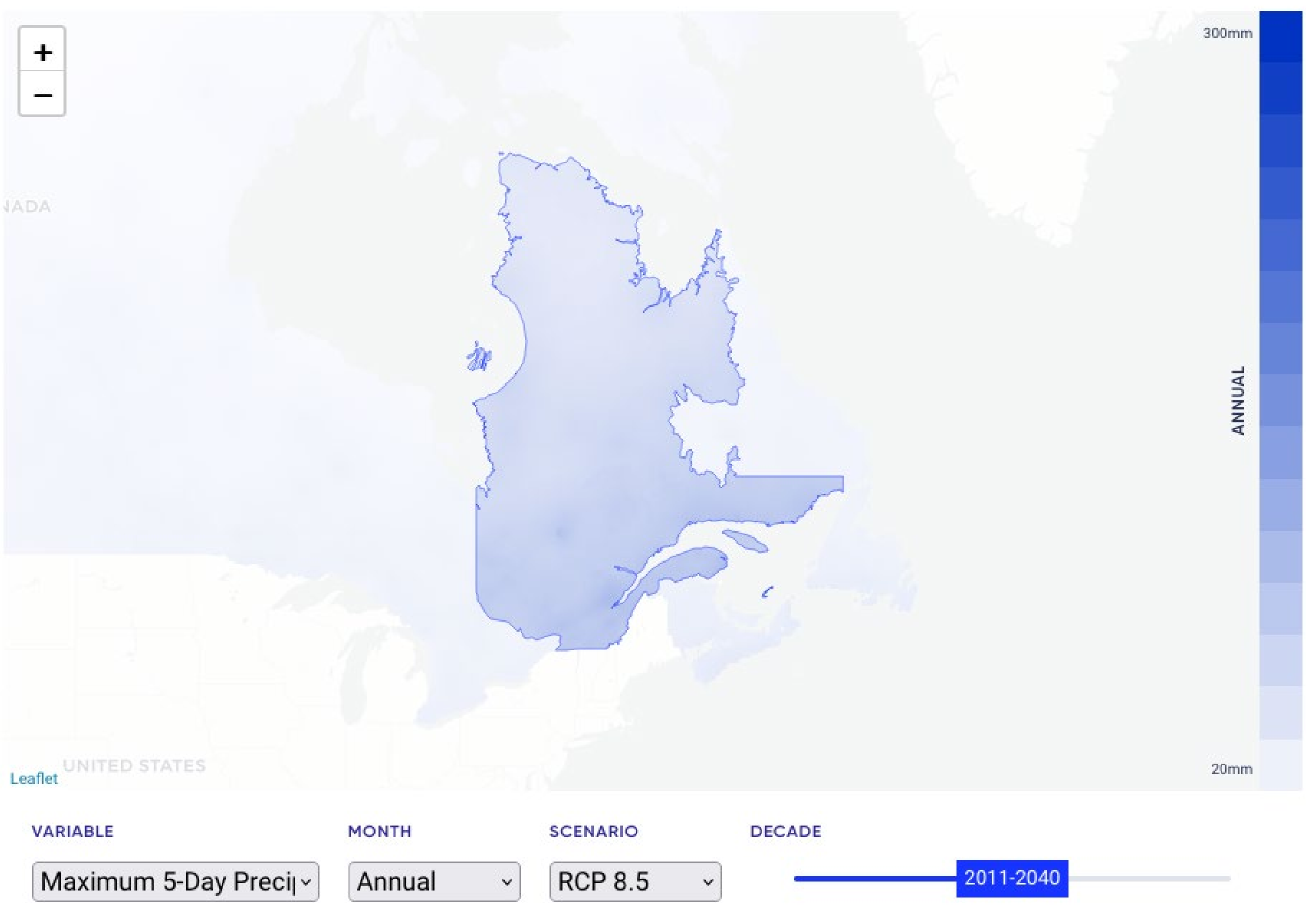
Quebec's lakes and rivers, including the St. Lawrence River, will be affected by climate change, which will modify water levels, flood risks, and water availability and quality. In response to potential changes in water regimes, Quebec is implementing adaptation measures, such as updating flood zone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

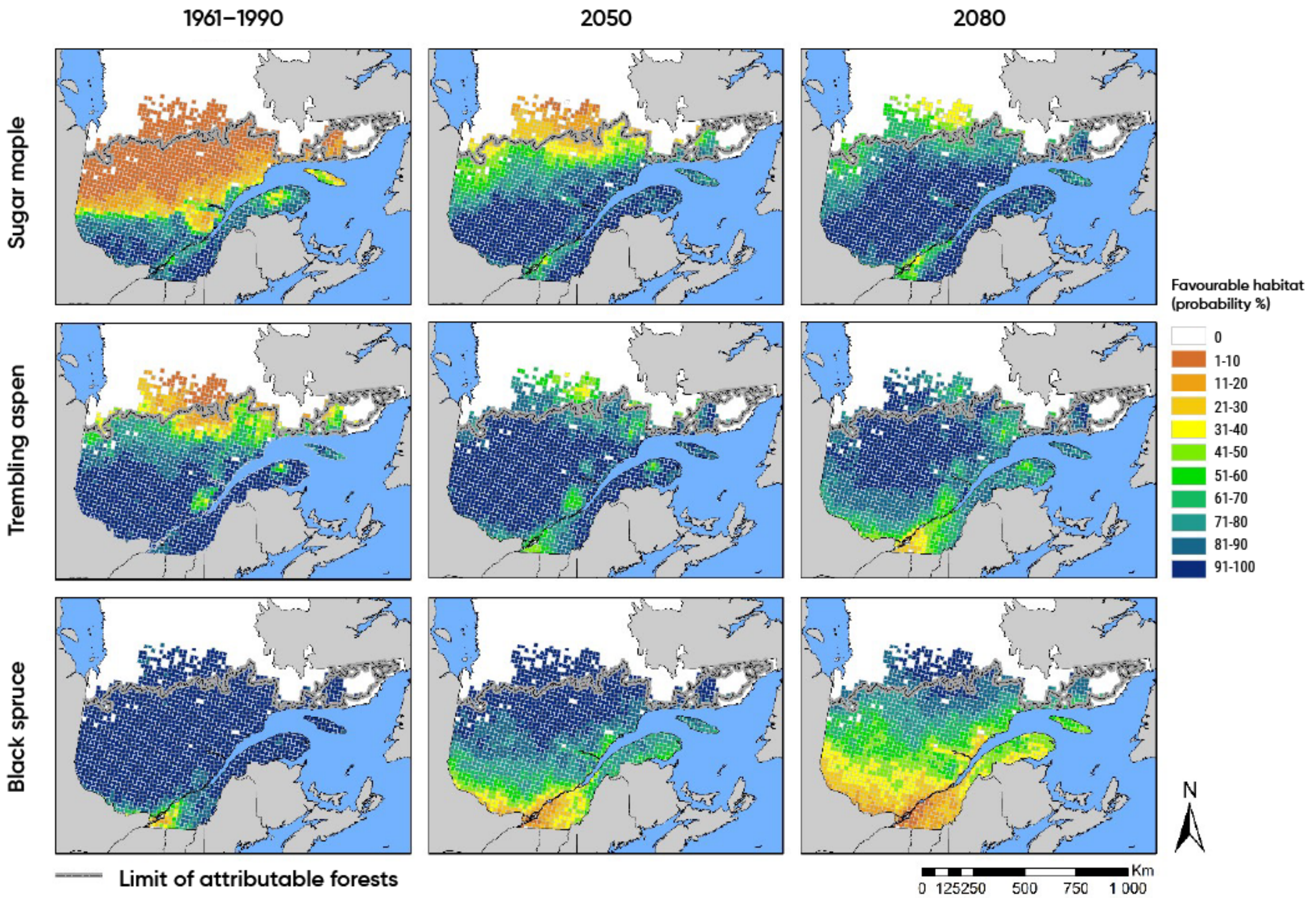


Figure 2.12: Probability of suitable habitats for sugar maple, trembling aspen and black spruce in 2050 and 2080 relative to 1961–1990. Source: Périé et al., 2009.

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).

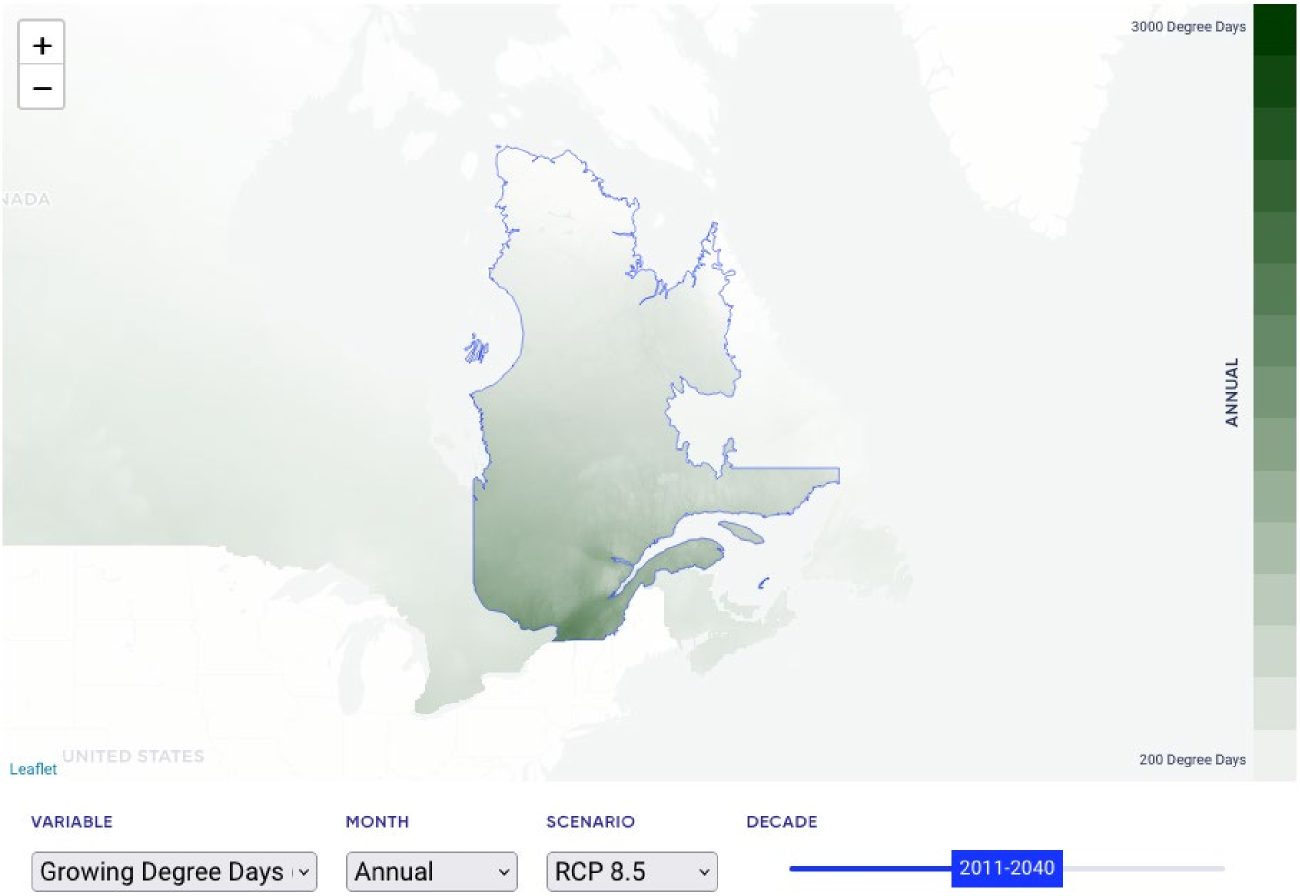
Commercial fisheries tend to target lobster, shrimp, crab and groundfish, and are critical to maritime regions (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2018). The fisheries sector accounted for more than 8,000 jobs in 2017 in the maritime regions of Quebec, and landings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

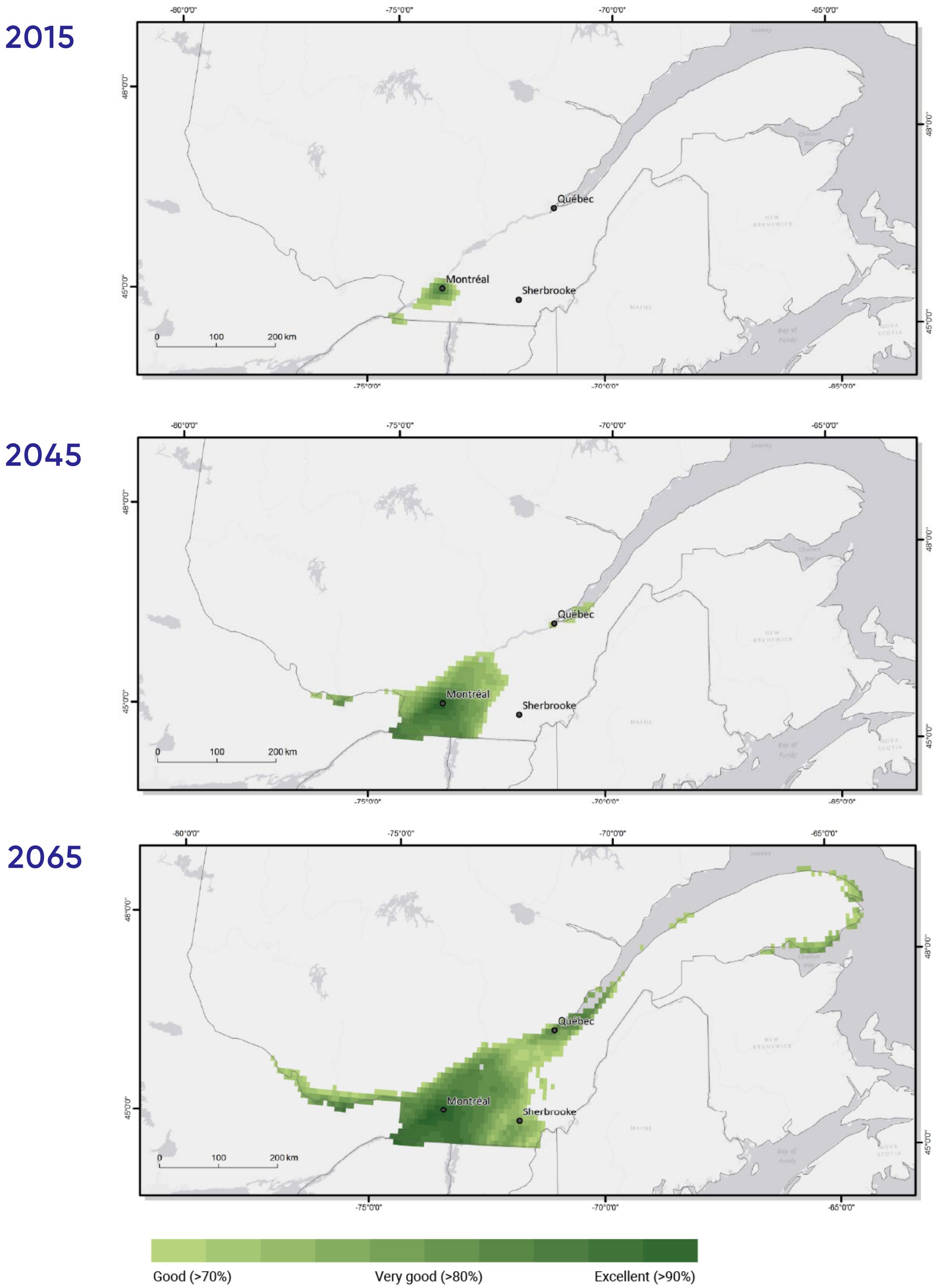


Figure 2.14: Trends in the viticultural potential of the St. Lawrence Valley according to a combination of RCP 4.5 and 8.5 scenarios. Source: Roy et al., 2017b.

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).

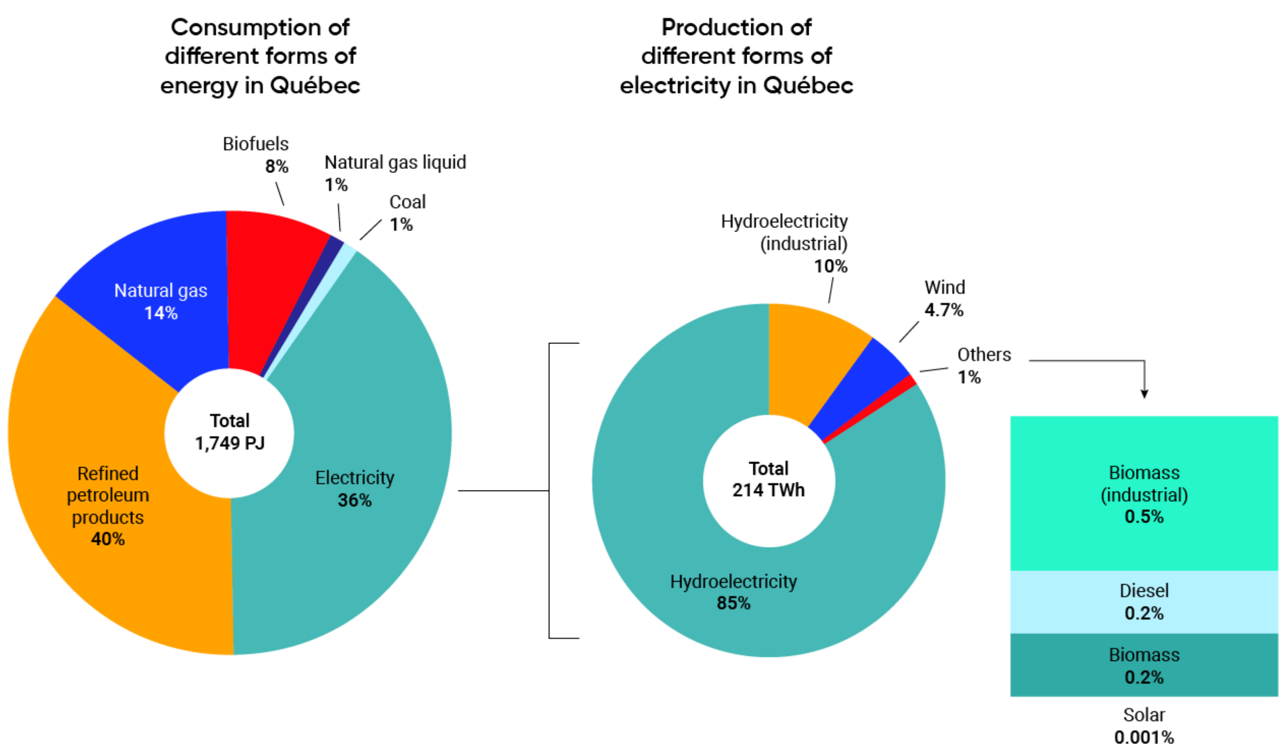


Figure 2.15: Total consumption by energy type in Quebec in 2017 (left) and electricity production by energy source in Quebec in 2018 (right). Source: Whitmore and Pineau, 2020.

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.

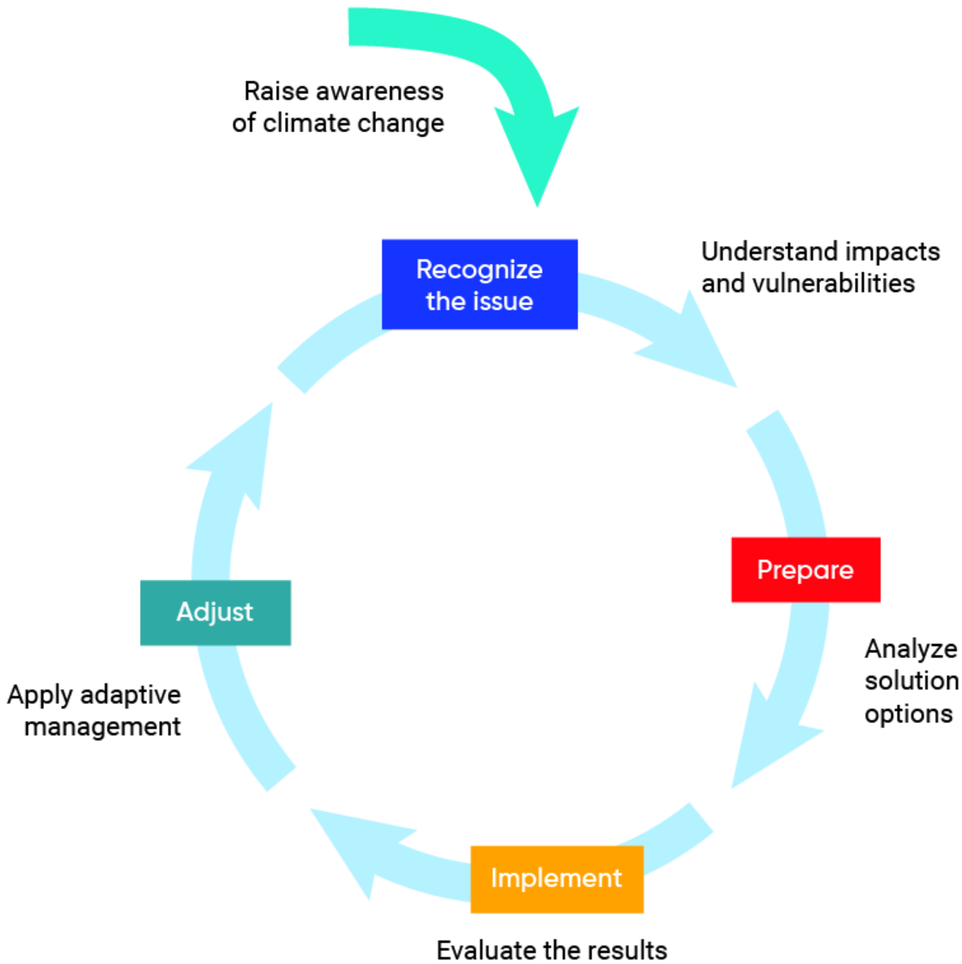


Figure 2.16: Climate change adaptation cycle.

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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