CHAPTER 7

Sector Impacts and Adaptation

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Table of contents

Key messages 493

7.1 Introduction 495

7.2 Sustainable forest management is challenged by wildfires and pest outbreaks 496

7.2.1 Introduction 496

7.2.2 Impacts of wildfire 497

Case Story 7.1: The 2016 Fort McMurray (Horse River) wildfire 502

7.2.3 Adaptation 505

7.2.4 Moving forward 506

7.3 Changes to ocean health are affecting fisheries and associated livelihoods 506

7.3.1 Introduction 506

7.3.2 Water temperature 507

Case Story 7.2: Impacts of the 2013–2015 marine heat wave on Canada's west coast 507

Case Story 7.3: Response of snow crab to rapid warming in Atlantic Canada 509

7.3.3 Dissolved oxygen 509

Case Story 7.4: Vulnerability of Greenland halibut in the Gulf of St. Lawrence 510

7.3.4 Acidification 512

Case Story 7.5: Lobster production in Atlantic Canada impacted by ocean acidification 512

7.3.5 Moving forward 513

7.4 Climate change brings benefits and threats to the agriculture sector 514

7.4.1 Introduction 515

7.4.2 Climate risks and regional adaptation planning 515

7.4.3 Inter-connectivity 517

7.4.4 Moving forward 518

7.5 Climate change brings new environmental challenges for mining 519

7.5.1 Introduction 519

7.5.2 Tailings containment structures 520

7.5.3 Reclamation of mining sites 521

Case Story 7.6: Reclamation of the Lorraine, QC mine site 522

7.5.4 Adaptation 524

7.5.5 Moving forward 525
7.6 Each link of the energy value chain can be vulnerable to climate change 526
7.6.1 Introduction 526
7.6.2 Risks to energy production and transmission 527
7.6.3 Adaptation 529
Case Story 7.7: Opportunities for increased hydropower production in Iceland 530
7.6.4 Moving forward 531
7.7 Extreme weather events impact transportation, disrupting supply chains 532
7.7.1 Introduction 532
7.7.2 Climate impacts on transportation systems 535
7.7.3 Understanding interdependencies 535
7.7.4 Adaptation 536
Case Story 7.8: Addressing increasing flood risk in Surrey, BC 537
7.7.5 Moving forward 539
7.8 Climate change is leading to transformational changes in tourism 540
7.8.1 Introduction 540
7.8.2 Winter sports tourism 541
7.8.3. Arctic cruise tourism 542
Case Story 7.9: The costs of increased tourism ship traffic in the Canadian Arctic 543
7.8.4 “Last chance” tourism 544
7.8.5 Moving forward 545
7.9 Increased private sector involvement will accelerate adaptation across sectors 545
7.9.1 Introduction 546
7.9.2 Corporate adaptation in Canada 546
7.9.3 Adaptation actions 547
Case Story 7.10: Insurance and climate change adaptation in Canada 548
7.9.4 Knowledge gaps 548
7.9.5 Moving forward 549
7.10 Moving forward 549
7.10.1 Knowledge gaps and emerging issues 549
7.11 Conclusion 551
7.12 References 553

Key messages

Climate change affects almost every economic sector in Canada (*see* Section 7.1)

Virtually every sector of the Canadian economy is affected, directly and/or indirectly, by climate change. Assessments of risks and opportunities that consider connections within and between sectors can help establish priorities for investments in adaptation actions.

Sustainable forest management is challenged by wildfires and pest outbreaks (*see* Section 7.2)

The forest sector is dealing with a wide range of climate change risks, from pest outbreaks to wildfire and long-term species shifts. The impacts of extreme events, such as wildfire, highlight the need for actions that build more resilient forests and communities, and that contribute to climate change mitigation.

Changes to ocean health are affecting fisheries and associated livelihoods (*see* Section 7.3)

Changes in ocean temperature and chemistry are already affecting fish populations. While some future impacts will be positive, many will present challenges to harvesters' economic livelihoods and regulators' responsibility for sustaining ocean health. Effective management depends upon realistic models of the future abundance and distribution of commercial species in response to both climatic and non-climatic stressors.

Climate change brings benefits and threats to the agriculture sector (*see* Section 7.4)

Climate change brings both opportunities and challenges to Canada's agricultural sector. Longer growing seasons and the potential to grow crops farther north may benefit agriculture, while changes in water availability, extreme weather events, and pests and diseases will present challenges. Adaptation actions that enhance climate resilience and consider the linkages between agriculture and interconnected sectors, such as water management and transportation, will benefit both local sustainability and global food security.

Climate change brings new environmental challenges for mining (*see* Section 7.5)

Impacts on the chemical and physical stability of tailings containment and reclamation structures are among the greatest climate-related challenges to the Canadian mining industry. Failure of such structures can lead to severe environmental contamination and present risks for surrounding communities and ecosystems. Considering long-term climate change at the design phase of mining projects is necessary to reduce these risks.

Each link of the energy value chain can be vulnerable to climate change (*see* Section 7.6)

Changing climate affects energy demand and the full energy value chain, from exploration and production through to transmission and distribution. Climate risks can be integrated into current business planning by considering co-benefits, no-regret options and incremental approaches. Climate resilience needs to be a key consideration in converting to low-carbon energy systems.

Extreme weather events impact transportation, disrupting supply chains (*see* Section 7.7)

Road, rail, marine and air transportation in Canada are vulnerable to "extreme weather events and slow-onset climate change, with major disruptions having significant economic and social impacts. To fully assess these impacts, linkages between transportation systems, and between transportation modes and a wide range of other economic sectors, need to be accounted for. Coordinating adaptation responses across jurisdictions and sectors will benefit transportation asset owners, operators and those dependent on vulnerable supply chains and corridors.

Climate change is leading to transformational changes in tourism (*see* Section 7.8)

All tourism destinations need to adapt to climate change impacts on tourism assets and altered competitiveness within the highly interconnected tourism economy. While Canadian tourism competitiveness is expected to increase under climate change, the specific market and regional implications of this change for national competitiveness remain under-researched. Winter and northern tourism and recreation are particularly sensitive to climate variability, and transformational changes in ski, snowmobile and Arctic cruise tourism are expected.

Increased private sector involvement will accelerate adaptation across sectors (*see* Section 7.9)

Despite growing awareness of climate change impacts, there is no widespread evidence of corporate adaptation in Canada. When adaptation does occur, it tends to focus on short-term actions to address physical risks, such as disruptions in construction and interruptions in supply chains. Increased involvement of the private sector would accelerate adaptation in Canada as a whole.

7.1 Introduction

Virtually every sector of the Canadian economy is affected, directly and/or indirectly, by climate change. Assessments of risks and opportunities that consider connections within and between sectors can help establish priorities for investments in adaptation actions.

It is increasingly evident that climate change is impacting Canada's economy as a whole, and that these impacts will increase in future (Canadian Council of Academies, 2019). Adaptation will be necessary across all sectors to limit climate risks and, in some cases, to benefit from new opportunities. Proactive adaptation enables innovation and growth, and can enhance economic competitiveness (Kovacs and Thistlethwaite, 2014). Very few studies have undertaken quantitative economic analysis of the impacts of specific climate scenarios on Canadian business and industry (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter; Eyzaguirre, 2016), but research elsewhere demonstrates that costs accelerate with continued warming (IPCC, 2014). Additionally, at higher rates of climate change, adaptation options become increasingly limited, presenting critical risks ranging from local economic viability to global food security (IPCC, 2019, 2018, 2014).

From a Canadian perspective, most sectoral research on impacts and adaptation has focused on food and natural resource sectors where climate change directly affects primary production, such as agriculture, fisheries, forestry and hydroelectricity generation (Warren and Lemmen, 2014). The economic significance of these sectors is amplified at both the local scale, with many Canadian communities deriving 80% or more employment income from these sectors (*see* Rural and Remote Communities chapter), and on the global scale, where Canada is among the world leaders in agriculture, forestry and mineral exports.

Less attention has been paid to other sectors of Canada's economy, with the exception of human health (Berry et al., 2014). However, there is growing recognition that climate-related health and social impacts on communities and workers, as well as climate impacts on supply chains and other infrastructure, represent significant material and financial risks throughout the economy (Canadian Council of Academies, 2019). As a result, a growing body of literature on these other sectors is emerging (*see* Climate Disclosure, Litigation and Finance chapter).

Previous sectoral assessments conducted in Canada, such as Warren and Lemmen (2014)—particularly chapters 4, 5 and 6—highlight:

- Vulnerabilities to both extreme weather events and to slow-onset climate changes;
- Amplified impacts in northern and remote communities;
- Opportunities that climate change presents for many sectors, in addition to the changing nature of climate risks;
- Increased implementation of climate adaptation measures and expanded engagement of industry, governments and civil society; enhancing both social and economic resilience;
- Processes that can help advance adaptation actions, including risk disclosure, environmental assessment and sustainable management reporting;

- Interdependencies between sectors, with transportation systems being particularly important; and
- A lack of information related to indirect impacts of climate change, including those related to consumer demand, supply chains, real estate or other assets, legal liability and government regulation.

This chapter builds on the findings of Warren and Lemmen (2014) and other relevant Canadian assessments (e.g., Palko and Lemmen, 2017) by examining key climate change impacts and adaptation in seven sectors of Canada's economy—forestry, agriculture, fisheries, energy, mining, transportation and tourism—as well as broad perspectives on corporate adaptation. Issues related to human health are not included in this chapter, as they are addressed in a separate assessment report (*see Health of Canadians in a Changing Climate Report*). The authors focused on a limited number of priority issues identified through assessment of the breadth of available knowledge. As a result, the subsequent sections of this chapter do not provide a comprehensive assessment of climate change impacts and adaptation responses within each sector, but rather focus on topics where knowledge has advanced recently and where the assessed knowledge relates directly to the ongoing decision-making process.

7.2 Sustainable forest management is challenged by wildfires and pest outbreaks

The forest sector is dealing with a wide range of climate change risks, from pest outbreaks to wildfire and long-term species shifts. The impacts of extreme events, such as wildfire, highlight the need for actions that build more resilient forests and communities and contribute to climate change mitigation.

Climate variability and extreme weather events associated with climate change are challenging forest management by limiting access to forest resources and increasing operational costs. More frequent wildfires and forest pest infestations are constraining local timber supplies and impacting the social and economic well-being of forest communities. In addition, the forest sector is facing longer-term climate impacts, such as changes in tree species composition, stand structure, productivity and health. In response to these and other challenges, such as changing social values and market demand, forest companies are addressing multiple environmental, economic and social needs simultaneously. Adaptive, risk-based management approaches that apply research, monitoring and evaluation will help inform future management policies to promote healthy, resilient forests and enhance carbon storage.

7.2.1 Introduction

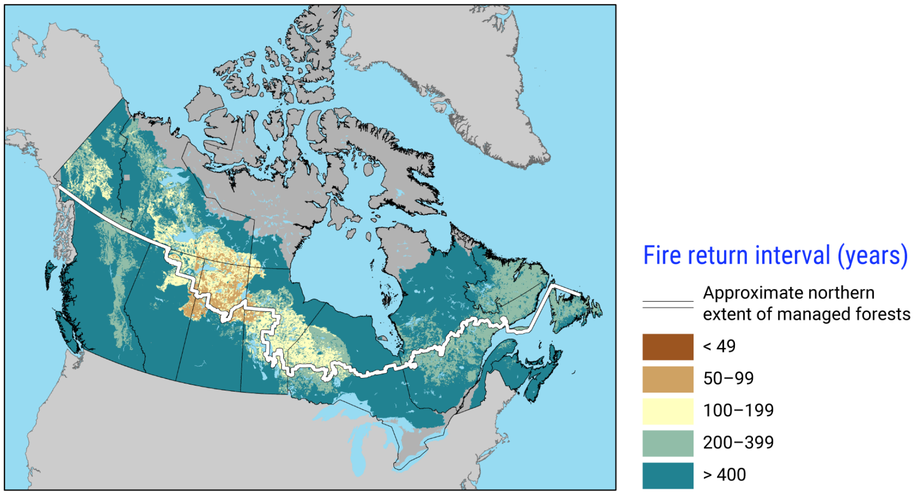
The Canadian forest sector is sensitive to the impacts of climate on ecosystem goods and services. In the short term, projected increases in temperature will likely surpass the potential moderating effects of increasing precipitation on fire weather (Zhang et al., 2019), leading to an increased risk of wildland fire and drought (Boucher et al., 2018; Boulanger et al., 2017; Flannigan et al., 2009). Climate change is also a critical driver of progressive disturbances, such as pest infestations, which influence the likelihood of immediate disturbance events, while also affecting long-term forest structure and composition (Sulla-Menashe et al., 2018; van Lierop et al., 2015; Price et al., 2013; Sturrock et al., 2011; Burton, 2010). The cumulative effects of these changes decrease the health and resilience of Canada's forests, constraining timber supply and increasing risks to the forest sector (Boucher et al., 2018; Taylor et al., 2017; McKenney et al., 2016; Gauthier et al., 2014; Price et al., 2013; Coulombe et al., 2010; Williamson et al., 2009). Better understanding of these projected changes will help the forest sector better prepare for both risks and opportunities.

Past management responses to climate-related impacts in the forestry sector have tended to be reactive, as exemplified by responses to the mountain pine beetle outbreak in Western Canada (Jones and Preston, 2011; Bentz et al., 2010; Williamson et al., 2009). Recently, forest managers, policy specialists and researchers have developed an array of knowledge resources, tools, and protocols to help practitioners and stakeholders take a proactive approach to managing the impacts of a changing climate and related environmental and socioeconomic stressors. The phases of adaptive management are reviewed in a series of past assessments (Gauthier et al., 2014; Lemmen et al., 2014; Price et al., 2013; NRTEE, 2011; Williamson et al., 2009), recognizing that no single "road map" exists to guide the implementation of adaptation responses (Samy et al., 2015). This section builds upon past assessments by focusing on wildland fire in the context of recent events.

7.2.2 Impacts of wildfire

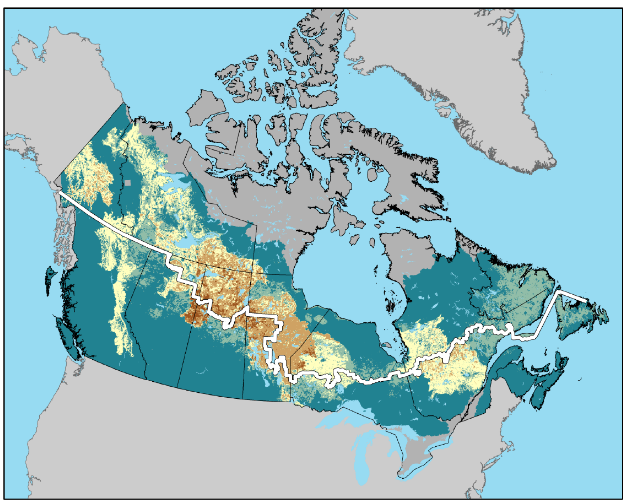
While forest fires are a natural and essential element of forest ecology, there is growing awareness of the dramatic impact that wildfires have on Canadians. As climate changes occur, fire regimes are changing, often with increasing frequency, severity and size (Mori and Johnson, 2013; Flannigan et al., 2009). Non-climate factors, such as forest condition, forest management practices, land cover (Marchal et al., 2017) and cumulative disturbances are also important considerations in explaining these increases. The fire season is becoming longer, starting earlier in the spring and ending later in the fall (Zhang et al., 2019; Hanes et al., 2018; Jolly et al., 2015; Flannigan et al., 2013), with more frequent fires (expressed by a shorter fire return interval) expected throughout this century (*see* Figure 7.1).

Baseline (1981–2010)

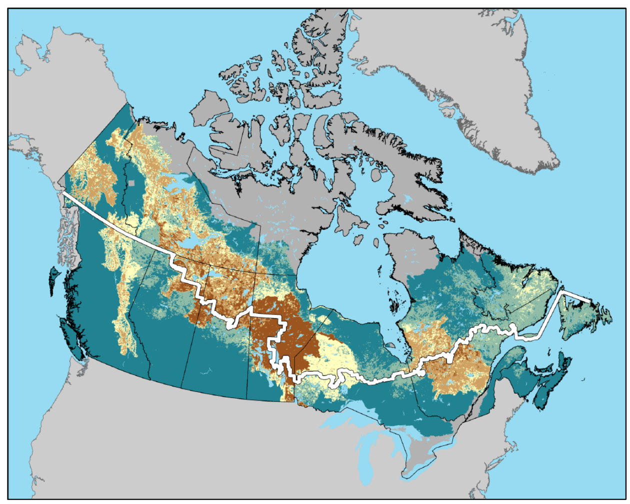


a)

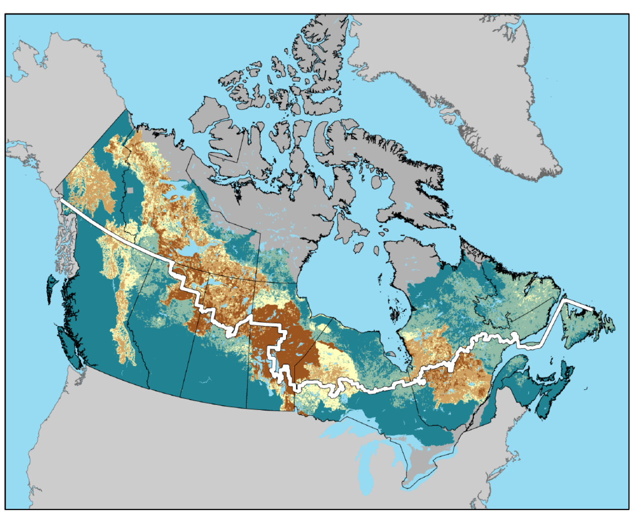
RCP2.6 (2011–2040)



RCP2.6 (2041–2070)



RCP2.6 (2071–2100)



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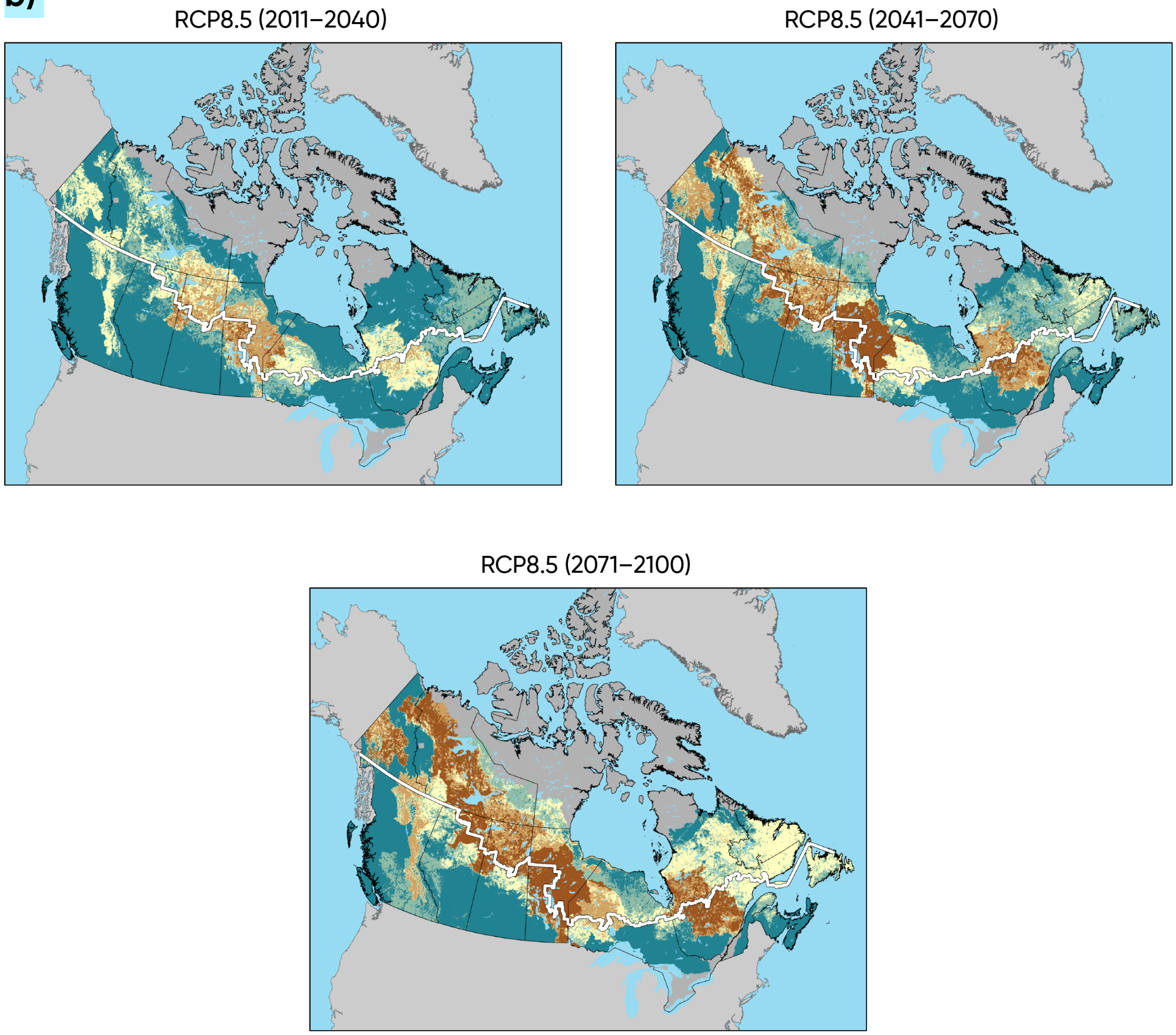

Figure 7.1: Interactive maps of baseline and projected fire likelihood in Canada, presented in terms of fire return interval (years), for two greenhouse gas (GHG) emissions scenarios: a) a low emissions scenario (RCP2.6) and b) a high emissions scenario (RCP8.5). Shorter fire return intervals (in brown and light brown) represent a higher fire likelihood, and longer cycles (in yellow, light and dark green) represent a low fire likelihood. The maps show local fire likelihood (pixels represent a 250 m² resolution) using the homogeneous fire regime zones of Boulanger et al. (2014) and display fire selectivity based on vegetation composition and stand age at the pixel level. Source: Boulanger et al., 2014.

Ecological impacts following wildfires include changes to forest stand structure, such as age class distribution and species composition (Price et al., 2013; Brown and Johnstone, 2012; Lynch, 2004). Shorter return intervals, in combination with growing fire severity, increase the risk of regeneration failure (*see* Figure 7.2; Whitman et al., 2019), and transitioning of forested areas to non-forested terrain (Boiffin and Munson, 2013; Price et al., 2013; Brown and Johnstone, 2012). Loss of tree cover on the landscape can lead to flooding and mass wasting in some areas (Bladon, 2018; Creed et al., 2016). Changes to fire regimes threaten not only timber supply (quality, quantity and tree species mix), but also the provision of ecosystem services, such as biodiversity, habitat for species at risk, carbon storage, water quality and water quantity (*see* Ecosystem Services chapter; Gauthier et al., 2014; Price et al., 2013). While it is difficult to predict how such changes will manifest locally, analysis of past mountain pine beetle infestations suggests that creating more resilient forests results in multiple benefits (Dymond et al., 2015).

Figure 7.2: Photo of a post-fire landscape at risk of regeneration failure: a site in the Northwest Territories, one year after a 2014 wildfire. This site had previously burned in 2004 and the short (10-year) interval between fires has led to a complete lack of tree recruitment. Poor regeneration is attributed to the absence of both seedlings and soil organic matter prior to the fire. Photo courtesy of Natural Resources Canada.

There is a growing awareness of the social impacts of wildland fire (McGee et al., 2015; Gill et al., 2013), including the numbers of wildfire evacuees (*see* Figure 7.3). Evacuations cause physical and mental health issues, disrupt the lives of evacuees and create economic stress on individuals and communities (McCaffrey et al., 2015; Beverly and Bothwell, 2011; Marshall et al., 2007; Morton et al., 2003). With more wildfires, health issues due to smoke are increasing well beyond the immediate vicinity of the fire (Liu et al., 2016; Reid et al., 2016; Finlay et al., 2012), and visibility issues are impacting transportation (Goodrick et al., 2013). To date, these impacts have disproportionately affected small and Indigenous communities: one third of all wildfire evacuees are Indigenous and over half of smoke-related evacuations involve Indigenous communities (*see* Rural and Remote Communities chapter; Sankey, 2018; Scharbach and Waldram, 2016; Christianson, 2015).

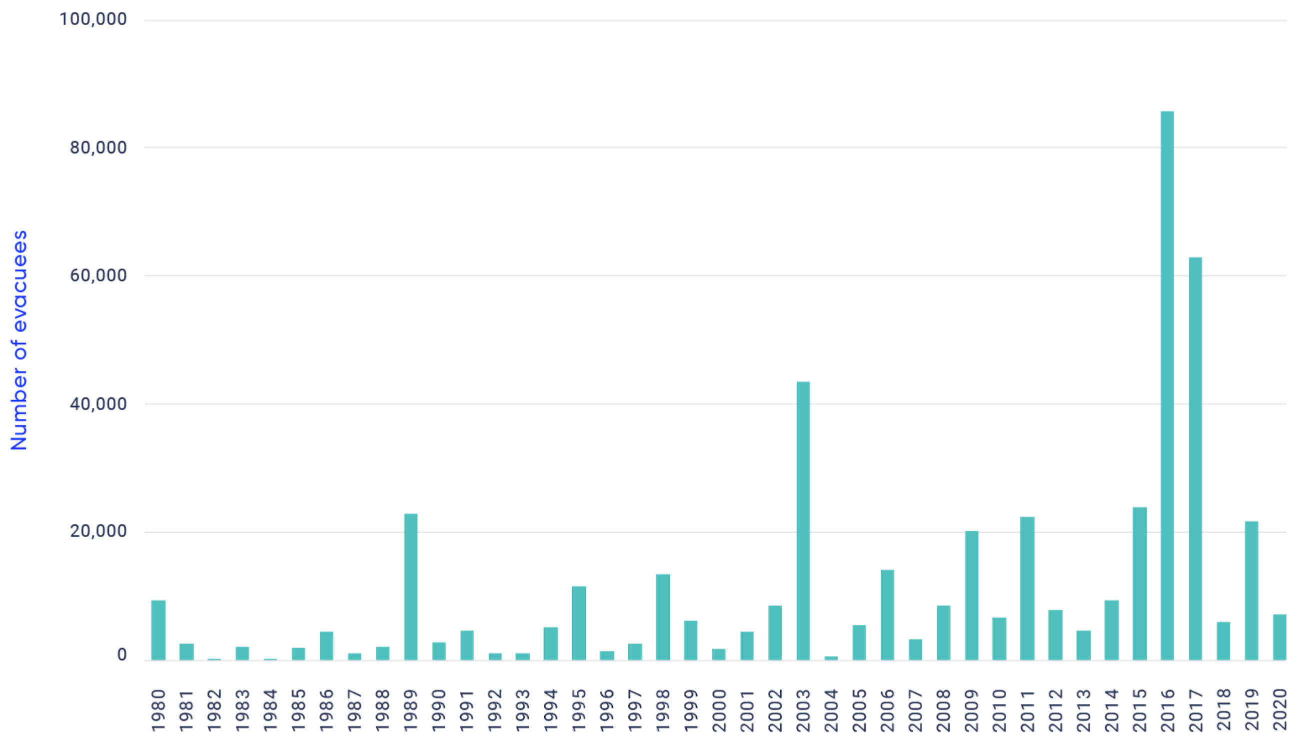

Figure 7.3: Number of wildfire evacuees in Canada (1980–2020). Many factors, including fire frequency, size and location relative to population density, influence the number of evacuees. British Columbia, Alberta, and Ontario have had the most evacuations from 1980 to 2020. Data source: Government of Canada, 2020.

Economic impacts associated with wildland fire are far-reaching. Direct costs, which include fire management and suppression activities (Rijal et al., 2018; Wotton et al., 2010), have increased from an average of $290 million per year in the early 1970s to about $1 billion annually in recent years (Natural Resources Canada, 2019, 2017). These costs are projected to further increase by over 100% by the end of the century under a high emissions scenario (Hope et al., 2016). Maintaining current effective levels of fire suppression appears to be unsustainable (Wotton et al., 2017; Hope et al., 2016). Climate change impacts and loss of timber supply have cascading economic impacts on the forest sector that are difficult to quantify (Ochuodho and Lantz, 2014). Other sectors also face direct costs from wildfires, including the following: evacuation expenditures; damage to infrastructure; shutdown of businesses and industries; insurance costs; and loss of forest ecosystem services (McGee et al., 2015; Gauthier et al., 2015; Peter et al., 2006). The increased emphasis on forests in the low-carbon economy highlights the importance of quantifying the costs associated with the release of greenhouse gases. There are also health costs associated with smoke and evacuation stress (Reid et al., 2016; McCaffrey et al., 2015; Beverly and Bothwell, 2011; Morton et al., 2003).

Catastrophic insurable losses due to extreme events such as wildfire are increasing. The Fort McMurray wildfire in 2016 was the largest insurance event in Canada, assessed at almost $4 billion (*see* Case Story 7.1; Insurance Bureau of Canada, 2019, 2016; Swiss Re Institute, 2018; Statistics Canada, 2017). This assessment vastly underestimates overall costs, given that uninsured costs for repairing and rebuilding for governments and homeowners can be three to four times those of private insurance companies (Dixon et al., 2018). The link between climate change and extreme events is clear (e.g., IPCC, 2012), with recent attribution analysis in Canada indicating that climate change has increased the likelihood of extreme dry conditions, extreme wildfire risk and the length of fire seasons (Kirchmeier-Young et al., 2017; Tett et al., 2017). All of these factors are relevant to the Fort McMurray wildfire (Zhang et al., 2019).

Case Story 7.1: The 2016 Fort McMurray (Horse River) wildfire

The Horse River wildfire began on May 1, 2016, seven kilometres outside of Fort McMurray, Alberta. Two days later, it entered Fort McMurray, destroying approximately 2,400 homes and displacing an additional 2,000 residents in three communities within the Wood Buffalo region (*see* Figure 7.4; MNP, 2017). Before it was controlled, the fire spread across northern Alberta into Saskatchewan, threatening First Nations communities, impacting Athabasca oil sands operations through lost oil production of approximately 47 million barrels—costing $1.4 billion in lost revenue (Antunes et al., 2016)—and consuming extensive forests and destroying critical infrastructure (MNP, 2017). The Insurance Bureau of Canada estimated insured losses at $3.9 billion, making it the costliest disaster in Canadian history and also one of the worst fire disasters internationally (Insurance Bureau of Canada, 2019, 2016; Swiss Re Institute, 2018).

a)

b)

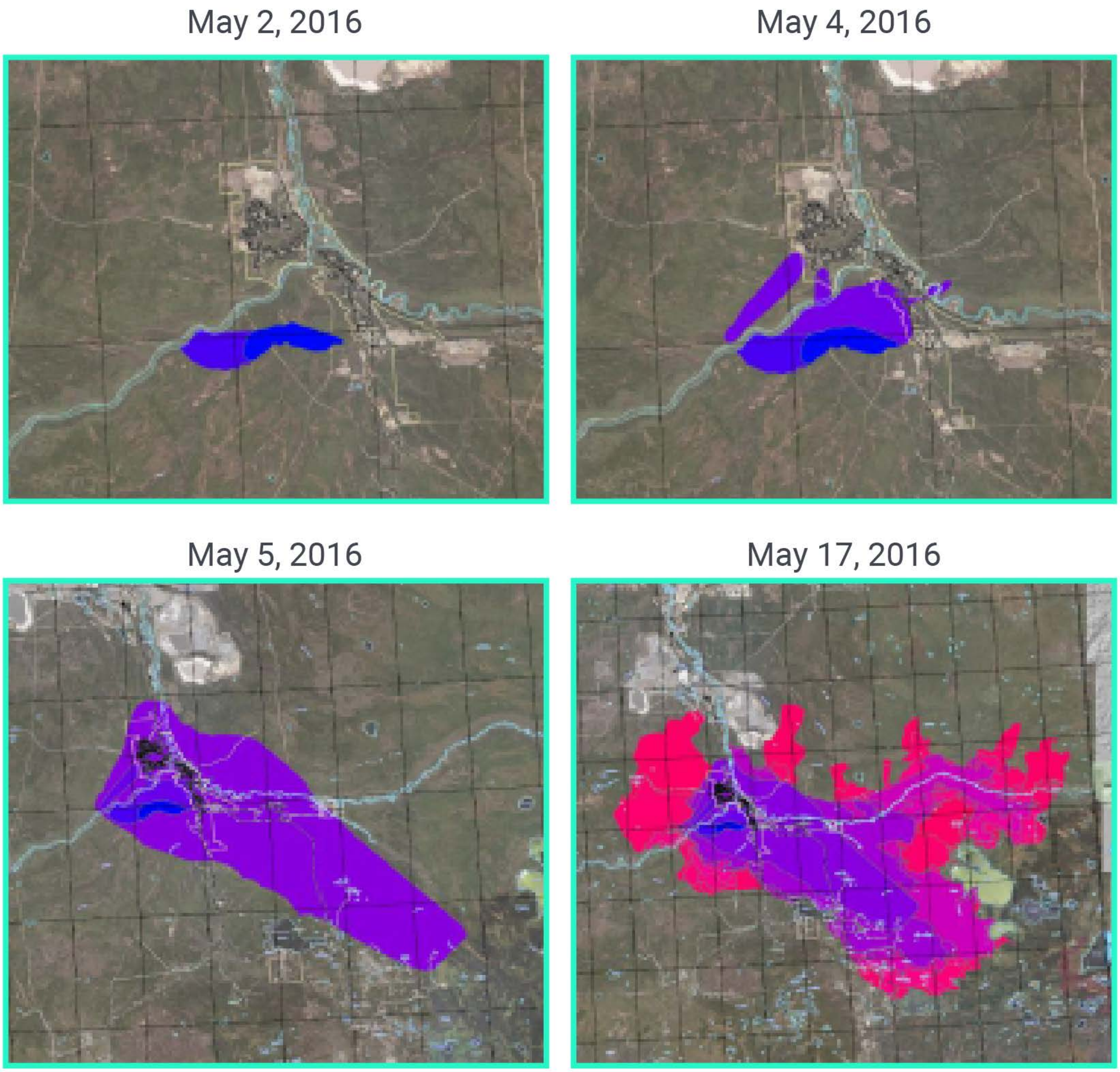

Figure 7.4: a) 2016 Horse River wildfire approach to Fort McMurray, Alberta; b) Maps outlining the growth of the 2016 Horse River Wildfire from May 2, 2016 to May 17, 2016. Source: Adapted from MNP, 2017.

Estimating the full costs of wildfires presents challenges due to the number of direct and indirect costs, ranging from economic damage to homes and infrastructure to the health care costs associated with atmospheric pollution from the fire and toxic discharges into watersheds (*see* Table 7.1). The Horse River experience illustrates how the impacts of wildfire can quickly expand beyond the forest sector to include numerous other sectors and disciplines, and highlights the importance of collaboration between institutional partners in dealing with the full impacts of climate change.

Table 7.1: Examples of direct and indirect costs associated with the Fort McMurray (Horse River) wildfire

DIRECT COSTS (EXAMPLES)
Suppressing and extinguishing wildfire across multiple jurisdictions
Evacuation activities, including the coordination and support of evacuees
Law and order maintenance during the evacuation
Damage to personal property
Damage to business infrastructure
Damage to public infrastructure (gas, power and telephone lines)
Commercial timber losses
INDIRECT COSTS (EXAMPLES)
Loss of oil production
Loss of non-oil industrial production, including retail and other commercial sectors
Unemployment (lost wages and salaries)
Demographic shifts (population decline and loss of productive workforce)
Social service costs, including long-term health care and family related-issues
Greenhouse gas emissions, the release of pollutants, and other impacts on ecosystem services
Insurance rate increases
Source: Based on Subedi et al., 2016.

7.2.3 Adaptation

Since the risks associated with wildfire and other climate impacts have effects beyond the forest sector, implementing adaptation measures requires the involvement of stakeholders across multiple sectors (Furness and Nelson, 2016; Nelson et al., 2016). Some adaptation options mentioned below are specific to wildfire, while others contribute to increasing the overall resilience of forests and forest communities (*see* Edwards et al., 2015 and Gauthier et al., 2014 for compendiums of adaptation measures).

Various adaptation options are available to reduce the risk and impacts of forest disturbances such as wildfire (Leduc et al., 2015; McGee et al., 2015; Blackwell et al., 2008). For example, fire risk can be reduced through active fuel management, involving thinning, debris removal and prescribed burning (Astrup et al., 2018; Schroeder, 2010; Ohlson et al., 2006; Spittlehouse, 2005), and adjusting harvest schedules to favour older and insect-damaged stands (Dymond et al., 2015; Raulier et al., 2014). Regeneration planning could include a greater proportion of more fire-tolerant species and deciduous trees (Bernier et al., 2016).

At the local level, FireSmart activities (Hirsch et al., 2001), such as creating fire breaks around communities, building with fire-resistant materials, and cleaning up debris around properties to reduce fuel load, help increase resilience to wildland fire (FireSmart Canada, 2019a, 2019b, 2018; Spittlehouse, 2005). Communities are actively improving their emergency preparedness by creating plans for culturally-sensitive evacuations and hosting of evacuees (Scharbach and Waldram, 2016; Beardy's and Okemasis' Cree Nation, n.d.).

While a number of adaptation responses have been developed to reduce the costs resulting from the effects of wildfire on timber supply (Rijal et al., 2018; Leduc et al., 2015; Raulier et al., 2014; Raulier et al., 2013); addressing the broader economic impacts of wildland fires extends far beyond the forest sector (Orwig, 2016). For example, the insurance sector is examining the impact of wildland fires on mining, forestry, energy, agriculture, transportation and utilities, and is collaborating with organizations such as FireSmart (Hirsch et al., 2001) to incentivize actions to reduce fire risks around communities and infrastructure.

The status of implementation provides a benchmark for measuring adaptation progress in the forest sector. The Canadian Council of Forest Ministers' Climate Change Task Force produced a series of nine interrelated reports (Canadian Council of Forest Ministers, n.d.), including a practical guidebook (Edwards et al., 2015), to support mainstreaming of climate change into forest management planning. Early adopters are using this guidebook to assess vulnerabilities and rank adaptation options based on current and future ability for implementation (Andrews-Key, 2018; Gatin and Johnston, 2017). Guidance documents have also been produced to help private woodlot owners adapt to a changing climate (Ontario Woodlot Association, 2015). National and regional climate change initiatives (e.g., Gatin and Johnston, 2017) include climate change strategies and action plans, and updated policies and regulations. Supportive research has placed an emphasis on integrated assessment approaches, drawing on expertise from a range of disciplines to complement ecological research with socioeconomic analyses.

7.2.4 Moving forward

Climate change is already affecting the forest sector, especially through extreme events such as wildfire. These effects are expected to continue and intensify, requiring greater efforts to implement adaptation measures. While no single road map exists to guide adaptation implementation, regional risk assessments in Canada have highlighted the need for integration of ecological, social and economic pressures beyond the forest sector. Integration and the capture of synergies across sectors can be greatly facilitated by adopting common data sources and scenarios (Environment and Climate Change Canada, 2018) as well as risk-based methods and frameworks (*see* Section 7.9; Johnston et al., 2020; ISO, 2018; Daniel et al., 2017; Calkin et al., 2014; Jones and Preston, 2011). Implementation of actions that enhance the climate resilience of forests is important for supporting the ecological, social and economic services that forests provide.

7.3 Changes to ocean health are affecting fisheries and associated livelihoods

Changes in ocean temperature and chemistry are already affecting fish populations. While some future impacts will be positive, many will present challenges to harvesters' economic livelihoods and regulators' responsibility for sustaining ocean health. Effective management depends upon realistic models of the future abundance and distribution of commercial species in response to both climatic and non-climatic stressors.

Climate change is increasing water temperatures and acidity, decreasing oxygen content and increasing the salinity of the world's oceans. Of these environmental variables, changes in temperature, dissolved oxygen and acidification will be responsible for most of the direct impacts on fisheries and aquaculture (farming of fish or shellfish) in Canada over the next few decades. These variables are driving, and will continue to drive, changes in distribution, productivity, reproduction and timing of seasonal events (e.g., moulting, migration, spawning and hatching) for many aquatic species. Extreme events, particularly abrupt warming events lasting many months, are also important considerations in aquatic management. Planning of adaptation measures needs to account for the complex interactions between various climate stressors, as well as non-climatic stressors such as fishing pressures.

7.3.1 Introduction

The critical role and climatic sensitivity of fisheries and aquaculture in food security at the global scale, and in local-scale resilience of coastal communities, are well established (Bindoff et al., 2019; Lemmen et al., 2016; Porter et al., 2014). An overview of climate change impacts on food production in Canada, and related adaptation actions, was presented by Campbell et al. (2014). For the fisheries sector, the researchers concluded that regional impacts from physical habitat changes, invading species, and societal responses will determine future patterns of use and overall economic implications. Aquaculture was noted as having the greatest scope for adaptation measures, making it less vulnerable and better positioned to take advantage of opportunities compared to capture fisheries, while traditional subsistence fisheries were deemed to be particularly vulnerable.

This section builds on the findings of Campbell et al. (2014) by focusing on near-term challenges for the sustainable management of marine ecosystems arising from physical habitat changes (e.g., warming, acidification, and lowering or depletion of dissolved oxygen), and highlights how climate change is being incorporated into scientific advice that informs fisheries and aquaculture management decisions. Greater details on the physical impacts of changing climate are described in Chapter 7 of *Canada's Changing Climate Report* (Greenan et al., 2019a). Impacts on freshwater recreational and commercial fishing and aquaculture are not discussed here, but it is clear that increased water temperatures and decreased pH and oxygen are already impacting many freshwater ecosystems. Additionally, it is noted that anadromous species will be subjected to negative impacts during their stay in freshwater, and therefore even marine fisheries will be affected by changes in freshwater ecosystems.

7.3.2 Water temperature

With a few exceptions, the internal temperature of fishes and crustaceans closely matches that of the water in which they live. As a result, temperature exerts a strong influence on their physiology (e.g., metabolism and growth) and aquatic animals are adapted to a species-specific temperature range. When mobile species encounter temperatures approaching their upper tolerance limit, they tend to move towards cooler, more optimal temperatures. Off the west coast of British Columbia, a persistent warming event from 2013 to 2015 had several ecosystem impacts (*see* Case Story 7.2).

Case Story 7.2: Impacts of the 2013–2015 marine heat wave on Canada's west coast

A well-documented warming event that started offshore of the west coast of British Columbia in 2013 was evident in coastal waters by the summer of 2015 (*see* Figure 7.5), with an increase in water temperatures of 3˚C above normal (Ross, 2016). This warming of coastal waters was accompanied by harmful algal blooms, record high levels of large gelatinous zooplankton and invasion by warm-water species (Chandler et al., 2016). The event may have had cascading ecosystem consequences, such as the extraordinary bloom of a colonial waterborne tunicate (an animal with no backbone that is rarely found north of California) observed along the entire west coast of North America in 2017 (Brodeur et al., 2018). While the specific causes are unknown, the 2013–2015 marine heat wave, coupled with favourable conditions for growth and reproduction, could have resulted in this unprecedented bloom. The bloom had substantial negative impacts on commercial and recreational fishing operations due to fouling of fishing gear (Brodeur et al., 2018), illustrating that anomalous events can have unforeseen impacts on coastal fisheries.

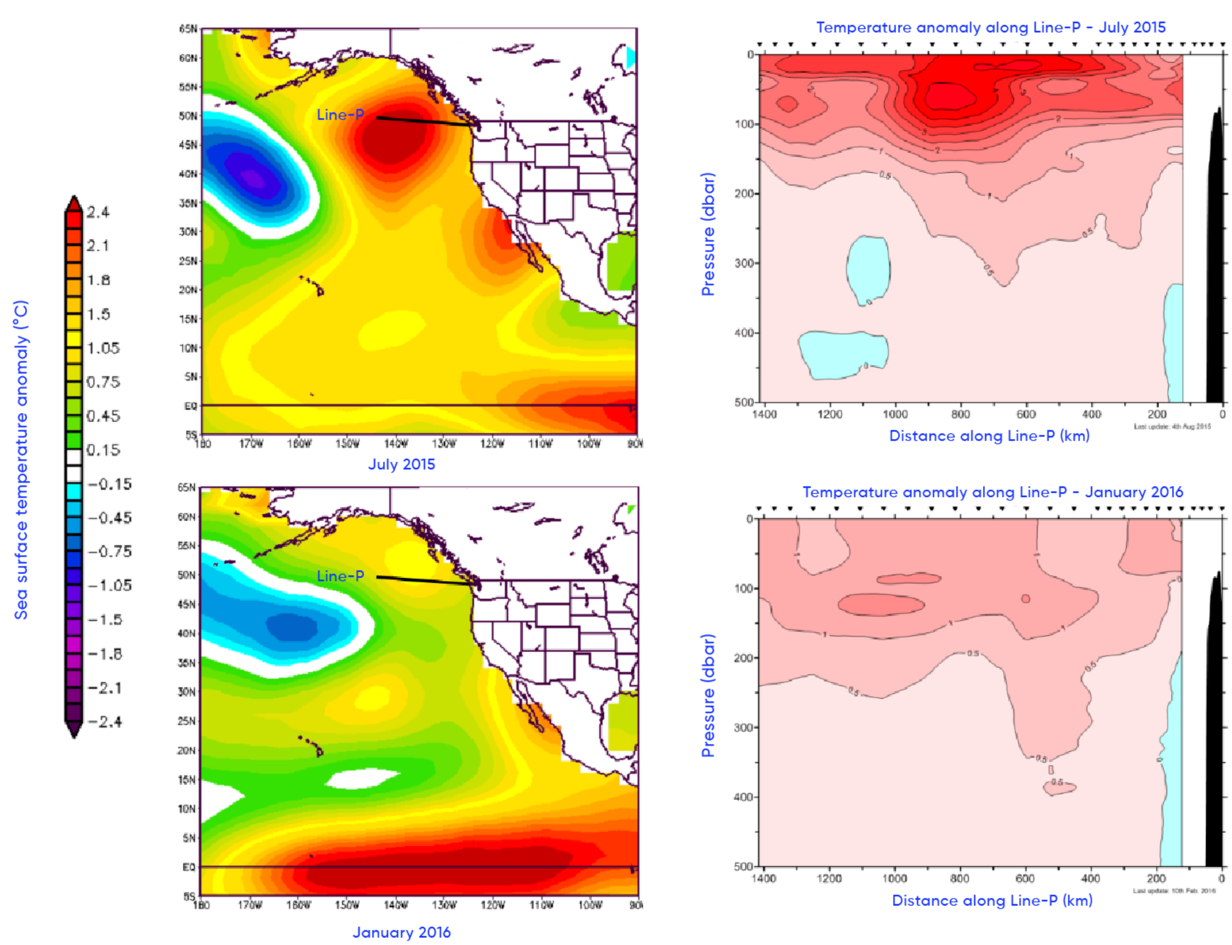

Figure 7.5: The left-hand panels show sea-surface temperature anomaly data (National Oceanic and Atmospheric Administration), including information from satellites, ships, and moored and drifting buoys. Temperature anomalies are the differences between the observed temperature and the long-term average temperature (both in °C) for a given location. The green, yellow and red colours represent above-average temperatures, whereas the blue and purple colours represent below-average temperatures. The right-hand panels show temperature anomalies by depth (in meters) along Line-P, as shown in the left-hand panels and starting near the southwest coast of Vancouver Island, BC, leading to the Ocean Station Papa (145°W, 50°N). The colours are demarcated by increments of 0.5°C. Source: Adapted from Chandler et al., 2016.

The general warming trends documented for the last century over most of the world's oceans have already resulted in distribution shifts (Mueter and Litzow, 2008). Changes in distribution of commercial species will cause changes in the location and success of fishing effort. Eventually, new species may replace old ones in the fisheries. Smaller movements or changes in abundance can also be observed at the regional scale, as fishes and crustaceans adjust their distribution to local changes in temperature (*see* Case Story 7.3).

Case Story 7.3: Response of snow crab to rapid warming in Atlantic Canada

Snow crab is a cold-water species with an upper thermal limit of 6–7°C. It is the second most valuable fishery in Atlantic Canada (Fisheries and Oceans Canada, 2018a). Its distribution has been shown to expand during cold periods and shrink in warmer periods (Ernst et al., 2005; Zheng and Kruse, 2000; Tremblay, 1997). An extreme warming event documented in the deep waters at the mouth of the Laurentian Channel off Nova Scotia, starting in 2012, propagated onto the Scotian Shelf, with temperatures reaching 7–9°C on the western Scotian Shelf (Brickman et al., 2018). This warming was accompanied by pronounced declines in catches in this fishing area, suggesting local mortality due to thermal stress in the absence of local colder refugia (Zisserson and Cook, 2017). The warming event also propagated into the deep channels of the Gulf of St. Lawrence and is still ongoing (Galbraith et al., 2018). In this ecosystem, changes in the distribution and abundance of snow crab and other important commercial cold-water species, such as Greenland halibut and Northern shrimp, have been partly caused by deep water warming of more than 1°C (Fisheries and Oceans Canada, 2018b, c, d).

Attribution of impacts must take into account the multiple climatic and non-climatic factors that affect species distributions. For example, fishing pressure, population size and bottom temperature all affect, to varying degrees, changes in the distribution of groundfish (Adams et al., 2018). This illustrates the importance of examining the joint role of fishing and climate in the distribution of fish stocks in order to provide sound scientific advice for management.

7.3.3 Dissolved oxygen

Fishes and invertebrates require oxygen to live, although they differ in their sensitivity to lack of dissolved oxygen (hypoxia). Each species has a minimum level of oxygen required for survival, with severe hypoxia resulting in habitat loss and changes in distribution for mobile species, and increased mortality for immobile (sessile) species (Breitburg et al., 2018). Moderate hypoxia limits the amount of energy that animals can spend (Claireaux and Chabot, 2016), which usually translates into reduced feeding and growth rates for individual animals (Hrycik et al., 2017; Townhill et al., 2016), and ultimately reduced productivity for affected populations.

Climate change will exacerbate hypoxia because warming reduces the solubility of oxygen, increases biological oxygen consumption, and reduces ventilation in the world's oceans, which increases residence time of deep water. Increased residence time means that fishes, invertebrates and bacteria have more time to remove oxygen through respiration, and deoxygenation becomes more pronounced (Breitburg et al., 2018). Modelling analysis of the impacts of increasing temperature and hypoxia in the Gulf of St. Lawrence indicates significant declines in biomass production (*see* Case Story 7.4).

Case Story 7.4: Vulnerability of Greenland halibut in the Gulf of St. Lawrence

Greenland halibut inhabiting the Gulf of St. Lawrence is the warmest water population of this cold-water species. The population faces chronic hypoxia over its entire distribution, with oxygen levels at less than 50% of saturation. Hypoxia is most severe (18–25% saturation) at the head of the main channels, including the St. Lawrence Estuary, which is the main nursery for this population. Both laboratory studies (Dupont-Prinet et al., 2013) and field sampling (Youcef et al., 2015) show that low oxygen levels reduce the feeding and growth rates of juvenile Greenland halibut. A distribution model based on environmental conditions and abundance predicts a reduction in the distribution and abundance of this species in the Gulf of St. Lawrence by mid-century (2046–2065) (*see* Figure 7.6; Stortini et al., 2017).

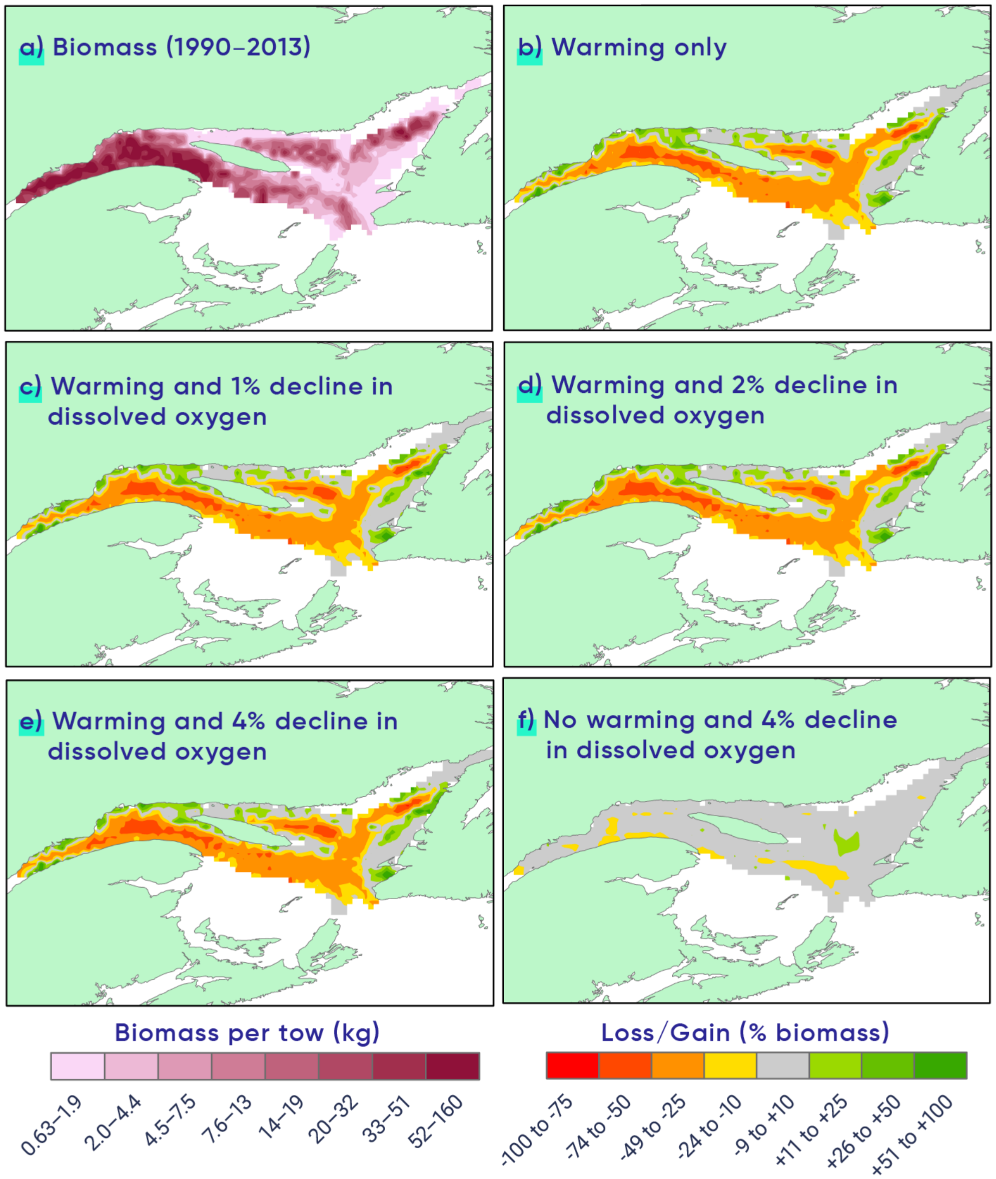

Figure 7.6: Results of five simulations for the distribution and abundance of Greenland halibut in the Gulf of St. Lawrence. a) Actual biomass data for the period 1990–2013. b) Scenario involving warming only. The scenarios shown in panels c), d) and e) involve the same level of warming as in panel b), but this warming is accompanied by different levels of oxygen decline (c = 1% decline, d = 2% decline, and e = 4% decline). f) Scenario with a 4% oxygen decline and no warming. The impacts of warming alone (b) and warming accompanied by a 4% saturation decline in dissolved oxygen (e) appear similar with the colour coding used, although warming alone reduced high-density areas by 49%, whereas the two stressors combined caused a 57% reduction. Decline in dissolved oxygen without the increase in temperature only reduced biomass by 2%. Source: Adapted from Stortini et al., 2017.

7.3.4 Acidification

Ocean acidification is caused by higher concentrations of CO_2 in the air, increasing the dissolution of CO_2 in the oceans to create carbonic acid and exceeding the ocean's ability to buffer against the increase in acid concentration. One measure of acidity is pH, with lower values representing a higher level of acidity. Since the Industrial Revolution, ocean pH has declined globally on average by 0.1 pH units, representing an increase of 26% in the number of hydrogen ions, and is predicted to further decrease by 0.4 pH units by 2100 under a high-emissions scenario (RCP8.5) (Ciais et al., 2013). Many studies have shown that the important commercial species of fish, shellfish, crustaceans and gastropods can suffer negative effects when exposed to acidified water (Alin et al., 2019; Parker et al., 2013; Kroeker et al., 2010). Ocean acidification has already had a massive impact on shellfish, where changes in seawater carbonate chemistry alter the ways in which juvenile (larval) shellfish build their shells, and can cause shell dissolution, deformities, slow growth and even death (Waldbusser et al., 2015; Gazeau et al., 2013). Ocean acidification impacts on shellfish aquaculture are evident through clear linkages between high CO_2 seawater concentrations and poor larval development of Pacific oysters in the United States shellfish industry (Barton et al., 2012). Shellfish hatcheries generating juvenile oysters for field outplanting were severely affected, with losses of money and jobs (Ekstrom et al., 2015). In the Atlantic, research is underway to examine the impacts of ocean acidification on the commercially valuable American lobster (*see* Case Story 7.5).

Case Story 7.5: Lobster production in Atlantic Canada impacted by ocean acidification

Lobster is the most lucrative fishery in Atlantic Canada. Key lobster production areas in the Gulf of Maine, Bay of Fundy and Scotian shelf are highly susceptible to ocean acidification due to poor regional buffering capacity and coastal nutrient inputs (Gledhill et al., 2015). Ocean acidification studies on both the early larval phases (stages I–IV) (Keppel et al., 2012) and early benthic phase juveniles (McLean et al., 2018) found slowed growth and an increased time between moults in more acidified seawater conditions. Low pH can also cause deformities in lobster larvae (*see* Figure 7.7). When lobsters are smaller and when they remain in the pelagic phase for longer periods, there is an increased likelihood of predation, therefore potentially limiting benthic recruitment (Keppel et al., 2012). Delayed growth of benthic juveniles also increases predation susceptibility (McLean et al., 2018), and ultimately affects population dynamics. Juvenile benthic lobsters in acidified conditions are also more susceptible to shell disease (McLean et al., 2018).

Figure 7.7: Healthy stage IV American lobster reared in ambient conditions (bottom) and a deformed stage IV lobster larvae under acidified conditions (top). The acidified lobster is smaller and claws have been lost due to environmental stress. Photos from a recent study at the St. Andrews Biological Station, Fisheries and Oceans Canada.

Warming will also influence lobster populations in other parts of eastern Canada. Larvae are particularly sensitive to warming (Waller et al., 2017). Settled lobsters are more tolerant of warming, which is projected to have a neutral or positive impact on lobster in the offshore areas of the Scotian Shelf (Greenan et al., 2019b). This is likely to be the case off Newfoundland and in the Gulf of St. Lawrence as well, except in some parts of Northumberland Strait where temperatures can exceed 23.5°C, a level that is avoided by lobster (Wilson and Swanson, 2005; Crossin et al., 1998). Furthermore, management adaptation is possible; protection of large individuals has been suggested as an adaption strategy for reducing the impact of warming (Le Bris et al., 2018).

7.3.5 Moving forward

Fish stocks are assessed using the best available evidence, produced through basic research and using research monitoring programs. The resulting data are used to create physical forecast models that enable a longer-term understanding of climate change. The known associations between species abundance and environmental variables can be used to assess species vulnerability to warming (Stortini et al., 2015), to project future available habitat, and to facilitate planned adaptation to changes in distribution and productivity (Stortini et al., 2017; Marras et al., 2015; Shackell et al., 2014).

Fisheries management combines scientific advice with social and economic information to make decisions about the fishery. Canada has initiated a process to incorporate climate change into science advice on fisheries, with initial emphasis on the stock assessment process as part of ecosystem-based management (Fisheries and Oceans Canada, 2018e). Commercial stocks are assessed and managed within stock area units, with borders separating distinct stocks. Climate change adds another layer of complexity to the assessment and management process, in that we anticipate changes in distribution/productivity within and across borders. Increased understanding of the impact of multiple stressors on fishes and aquatic invertebrates will make it possible to develop more realistic models of the future abundance and distribution of commercial species, providing a stronger scientific foundation for resource management strategies.

7.4 Climate change brings benefits and threats to the agriculture sector

Climate change brings both opportunities and challenges to Canada's agricultural sector. Longer growing seasons and the potential to grow crops farther north may benefit agriculture, while changes in water availability, extreme weather events, and pests and diseases will present challenges. Adaptation actions that enhance climate resilience and consider the linkages between agriculture and interconnected sectors, such as water management and transportation, will benefit both local sustainability and global food security.

Agriculture is inherently sensitive to climate. Increasing temperatures, shifting precipitation patterns, and changes in the frequency and intensity of some extreme climate events will affect crops and livestock operations, by both amplifying existing risks, and bringing new risks and opportunities. The type and degree of impacts will vary across agricultural regions and production systems. For example, increasing abundance of insect and disease species, and greater risk of new pests and diseases will impact crop and livestock health and could increase the risk of trade barriers. Additional risks arise from the sector's strong dependence on transportation systems to maintain access to markets—systems that are themselves vulnerable to climate change impacts. Improvements to on-farm management practices—including improved fertilizer management, adoption of no-till practices to minimize soil disturbance, and improved water-use efficiency—have enhanced the sector's climate resilience and illustrate a high capacity to adapt.

7.4.1 Introduction

While Canada's agriculture sector is intrinsically adaptive (Campbell et al., 2014), its ability to adapt is being challenged by the impacts of climate change, including a northward shift in distribution of many insect and disease species and new invasive species. Changes in temperature and precipitation patterns, discussed comprehensively in Zhang et al. (2019), will bring shifts in the distribution of crops. Despite the fact that precipitation is projected to increase for Canada as a whole, areas such as the southern Prairies and the interior of British Columbia are expected to see increased moisture deficits during the growing season (Zhang et al., 2019), increasing the importance of irrigation and good water management.

Canadian agriculture is also highly dependent on reliable transportation networks to ensure that inputs (e.g., seed, fuel, fertilizer, pest control products and equipment) are delivered in an efficient, cost-effective and timely manner, and to maintain access to domestic and international markets. Flooding and other extreme weather events will challenge Canada's grain handling and transportation system (Phillips and Towns, 2017).

Improvements over the last twenty-five years have made Canada's agriculture sector more climate-resilient (*see* Prairie Provinces chapter; Campbell et al., 2014). There has been an increased focus on collaboration between producers, researchers, and decision makers within interconnected sectors to assess impacts and implement new adaptation measures, and this will contribute to increasing the sector's sustainability. This section examines recent developments in understanding climate change impacts on agriculture in Canada and the critical inter-connectivity between agriculture and transportation. A more in-depth discussion of agriculture at the regional level can be found in the regional chapters (*see* Atlantic Provinces, Ontario, Quebec, Prairie Provinces and British Columbia chapters).

7.4.2 Climate risks and regional adaptation planning

Understanding climate risks to agriculture is informed by inputting observed and projected climate data into agricultural models (e.g., for crops, livestock, pests and diseases) to identify potential physical and economic impacts. Planning and implementation are required at various scales to target and identify actions within whole agricultural value chains, to inform on-farm impacts and to identify appropriate adaptation actions.

Analysis of climate change impacts on agricultural production in Canada, summarized previously by Campbell et al. (2014), continues to improve. Under medium-emissions (RCP4.5) and high-emissions (RCP8.5) scenarios, production of wheat (Canada's largest crop and greatest value export) and other spring-seeded grains is projected to increase by between 8% and 11% by the 2050s (2041–2070), relative to a 2006–2015 baseline, across most of Canada's agricultural regions (Qian et al., 2019; He et al., 2018). Increased heat stress could reduce canola yields across the southern Prairies, which will likely lead to a northward shift in crop production areas (Qian et al., 2018). Climate impacts on corn and soybean production in Canada remain less conclusive, with some studies showing increased suitability in Atlantic and central Canada, and opportunity for expansion in the Prairies, provided moisture limitations are not too restrictive (*see* Prairie Provinces chapter; Agriculture and Agri-Food Canada, 2018; He et al., 2018; Schauberger et al., 2017; Sauchyn and Kulshreshtha, 2008).

Severe moisture deficits by the 2050s are projected for certain areas of Canada under a high-emissions scenario (*see* Figure 7.8), which will particularly affect spring-seeded grain crops, such as wheat and barley. Water scarcity would be amplified by increased demand for water by other sectors, especially where irrigation and access to water are already important constraints on the sustainability of agriculture. Climate change is projected to increase variability in water supply, and to strain irrigation, drainage and flood control systems. For example, glacial meltwater, which contributes approximately 10% of summer flow in the Columbia River and Bow River, will be reduced to almost zero over the next 50 to 60 years as glaciers disappear (Derksen et al., 2019; Fyfe et al., 2017). Glacial water melt is very important for maintaining summer flows in the rivers of western Canada, during the key growing period. Increasing irrigation and on-farm water-use efficiency is a key adaptation mechanism. Currently, irrigation is practiced on 1.1 million hectares of Canada's 44 million hectares of arable land (2.27%). While there is irrigation in every province, over 90% occurs in Saskatchewan, Alberta and British Columbia.

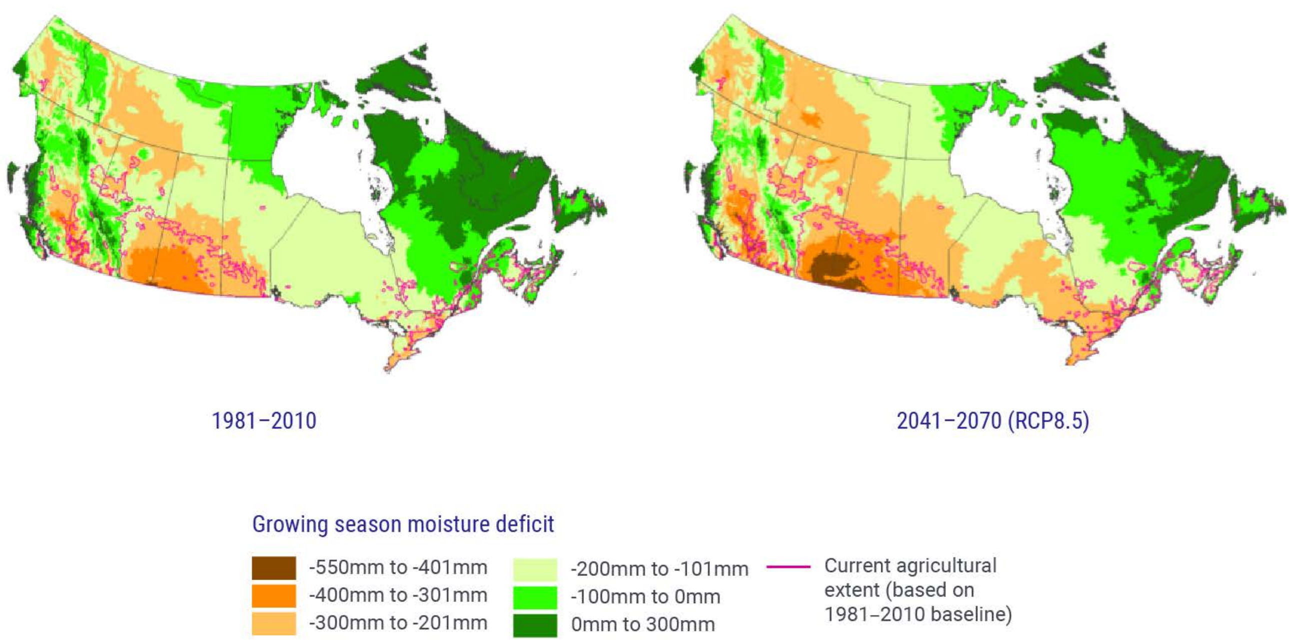

Figure 7.8: Growing season moisture deficit (precipitation minus potential evapotranspiration) across Canada for the period 1981–2010 and for the period 2041–2070 as projected under a high emissions (RCP8.5) scenario. In most areas, increased precipitation is more than offset by increased temperature and associated evaporation, leading to greater moisture deficits. Source: Agriculture and Agri-Food Canada, 2018.

The risks posed by animal diseases and plant pests are increasing as a result of climate change, with the likelihood of new invasive alien species (IAS) being introduced to Canada having significant consequences for Canada's agriculture sector and economy. It is estimated that invasive species currently cause $4.2 billion in annual measurable losses to Canada's agriculture industry (Agriculture and Agri-Food Canada and Canadian

Food Inspection Agency, 2008). These relate to reduced crop yields and revenue, increased IAS control costs, loss of access to export or domestic markets, and decreased native biodiversity resulting from competition for resources.

Modelling of pest and disease expansion under a changing climate indicates that the ranges of the striped flea beetle, *Phyllotreta striolata* (*Fabricius*), and the crucifer flea beetle, *P. cruciferae*, both IAS to North America, are projected to shift and potentially cause economic losses over an expanded area in the future (Olfert et al., 2017). Increased winter temperatures have contributed to higher overwinter survival of insect pests (Olfert et al., 2016) and some pathogens, including cereal rusts in the Prairie region (Xi et al., 2015; Kumar et al., 2013). The linkage between climate change and the rapid north and westward range expansion of the deer tick (*Ixodes scapularis*), which transmits the Lyme disease agent that can infect cattle and other livestock, as well as humans, is well documented (Ogden et al., 2014). Bluetongue, a viral disease of ruminants transmitted by the biting midge *Culicoides sonorensis*, extends from the southwestern United States into southern British Columbia and Alberta (Lysyk and Dergousoff, 2014), and has recently expanded into southern Ontario (Jewiss-Gaines et al. 2017). Species distribution models based on different climate change scenarios indicate that the range of *C. sonorensis* is likely to expand northward in Alberta (Zuliani et al., 2015).

Barriers to adaptation across the agriculture sector broadly (*see* Figure 1 of Campbell et al., 2014) include a lack of knowledge of climate impacts, limited technical capacity to assess agricultural risks at an appropriate scale, and uncertainties associated with projected climate impacts and adaptation actions (Agriculture Adaptation Working Group, 2016). Recent efforts by the agriculture sector to assess climate risks and consider adaptation actions, both regionally and at the farm level, have started to address these barriers. Examples include developments in climate risk assessment methodology and agricultural adaptation planning in Quebec (Ouranos, 2015), Manitoba (Goertzen, 2018), Nova Scotia (Nova Scotia Federation of Agriculture, 2018) and British Columbia (British Columbia Ministry of Environment and Climate Change Strategy, 2019). Continued work could further improve understanding of risks, the agricultural sector's awareness of climate impacts, and mechanisms to support adaptation action. New knowledge will continue to inform initiatives such as the agriculture sector's Emergency Management Framework (Federal, Provincial and Territorial Emergency Management Framework Task Team, 2016), which includes elements to help proactively manage the increasing risk of pests and diseases and potential associated trade risk issues.

7.4.3 Inter-connectivity

The success of agricultural production in Canada is highly dependent upon connections with transportation networks. A reliable transportation network allows for efficient delivery of necessary input goods (such as seeds, fuel, fertilizers and farm equipment), as well as access to export markets. Climate change presents a wide range of risks to transportation networks in Canada (*see* Section 7.7; Palko and Lemmen, 2017), including damage to infrastructure from extreme precipitation and flooding, impacts associated with sea-level rise and storm surge flooding at terminal ports, increased risk of rail buckling due to extreme heat, cracking of roadways as a result of desiccation of clay sub-soils during drought conditions and washouts during flooding.

All of these impacts can cause transportation delays that negatively impact the agriculture sector value chain (e.g., farmers, processors, suppliers, etc.) from local to international scales.

Canada's grain handling and transportation system is frequently impacted by extreme weather events. For example, excessive rainfall in Vancouver between January and March 2011, and severe weather events in the railway mountain corridors of British Columbia contributed to long delays in loading grain onto vessels in Vancouver ports (Quorum Corporation, 2014). Again in 2013, record totals of harvested crops in the Prairie provinces, followed by extreme cold winter conditions, contributed to transportation delays in accessing markets. Such delays impact Canada's reputation as a reliable supplier of agricultural products and result in added costs for both grain companies and producers (Gray, 2015; Quorum Corporation, 2015).

The importance of export markets for the Canadian agricultural sector cannot be overstated, with approximately 42% of its annual production being shipped out of the country. In 2013, Canada was the world's fifth-largest exporter of agriculture and agri-food products (Agriculture and Agri-Food Canada, 2016), with exports representing 85% of canola and canola products, 85% of flax, 66% of soybeans and soybean products, 65% of hogs and pork products, and 48% of cattle and beef products. Over the past 10 years, half of all Canadian grain production has been exported, averaging 41 million tonnes per year. Agri-food export sales in 2017 totalled $57.7 billion (Canadian Agri-Food Trade Alliance, 2020). While regional climate change impacts on agriculture production in Canada will be significant, impacts are expected to be much greater in most other major agriculture producing areas of the world (Food and Agriculture Organization, 2017; Ignaciuk and Mason-D'Croz, 2014). This represents both an opportunity for Canadian producers (Ignaciuk and Mason-D'Croz, 2014) and a critical need with respect to global food security (Mbow, 2019).

7.4.4 Moving forward

Mechanisms that support regional capacity to utilize and interpret climate change impacts and adaptation information are improving the ability of the sector to proactively plan and implement adaptation actions. It is also increasingly important for the sector to collaborate with other appropriate sectors, including transportation and water management, on shared adaptation issues. Initiatives such as Drought Watch (Agriculture and Agri-Food Canada, 2019), which provides information on current climate risks and provides a mechanism for producers to submit details on impacts experienced at the farm level, are an important step forward in enhancing engagement and collaboration.

7.5 Climate change brings new environmental challenges for mining

Impacts on the chemical and physical stability of tailings containment and reclamation structures are among the greatest climate-related challenges to the Canadian mining industry. Failure of such structures can lead to severe environmental contamination and present risks for surrounding communities and ecosystems. Considering long-term climate change at the design phase of mining projects is necessary to reduce these risks.

Climate change can affect every phase of a mine's life cycle. While short-term challenges, such as impacts on daily operations and disruption of critical supply chains, require adaptive actions, impacts on tailings containment and reclamation structures represent key vulnerabilities for the Canadian mining industry. Tailings containment and reclamation structures must remain in place for many decades and even centuries, which increases their vulnerability to climate change. While current designs of such structures take into account both average and extreme historical conditions, this does not adequately capture the full range of likely future conditions. Adaptation priorities include incorporating climate change projections into future designs, enhancing monitoring of existing structures and developing new methods and tools to improve climate resilience.

7.5.1 Introduction

Mining is a major component of the Canadian economy, with activities occurring in all provinces and territories. The effects of climate change on the mining sector are both direct and indirect, with the potential to affect every phase of a mine's life cycle (Bussière et al., 2017; Pearce et al., 2011; Stratos, 2009). In many cases, climate change will exacerbate existing climate risks and create new risks, but it will also afford some new opportunities (Stratos, 2017, 2009; Bussière et al., 2017; Pearce et al., 2011). For example, during the exploration phase, the shorter period of frozen ground will make it difficult to access some exploration sites. On the other hand, a longer warm season will allow more time for mapping and the delivery of raw material supplies by ship or floatplane.

An overview of climate change impacts and adaptation in the Canadian mining sector by Lemmen et al. (2014) highlighted risks to built infrastructure, transportation, extraction and processing, and daily operations. The project phases most affected are the management of mine tailings during operations and the reclamation of waste storage areas. These two phases have a long life span, and climate considerations are incorporated into their design (Bussière et al., 2017). Lemmen et al. (2014) also noted a lack of proactive adaptation planning for climate change in the sector, a conclusion supported by subsequent analysis that found little evidence of government or corporate policies having advanced in terms of addressing climate change impacts and adaptation (Stratos, 2017).

This section builds on previous Canadian assessments by focusing on what has emerged as a key climate vulnerability for the Canadian mining industry—risks to the physical and chemical stability of structures designed to contain tailings during and following mining activities, and risk to the long-term effectiveness of reclamation methods (Bussière et al., 2017; Stratos, 2017).

7.5.2 Tailings containment structures

Mining waste, composed of finely crushed rock and water, is stored in tailings ponds that are generally located at surface-level close to the mine (Blight, 2010; Bussière, 2007; Bussière et al., 2005; Aubertin et al., 2002). The purpose of these ponds is to contain the greatest possible volume of solid waste and permit the transfer of any overflow into one or more secondary ponds (called sedimentation and/or polishing ponds). These structures are usually created by closing off a natural valley or cordoning off an existing area with one or more dykes. They are equipped with drainage systems to allow the water, once solids settle, to be reused or processed, with spillways to control effluence during periods of extreme precipitation (Blight, 2010; Aubertin et al., 2002). Given the high water content and low density of most mine tailings, the physical stability of these structures is difficult to maintain over both the short and long term. Structures are frequently modified throughout the extraction stage of a mine (generally a few decades) to adapt to evolving operating conditions.

Current approaches to designing tailings containment structures consider both average and extreme climate parameters, such as probable maximum precipitation (PMP) and probable maximum flood (PMF) (Aubertin et al., 2015). PMP and PMF are based on frequency analyses of historical climate data, and have a low annual probability of recurrence (Canadian Dam Association, 2013; Aubertin et al., 2011; Koutsoyiannis, 1999). The use of PMF is recommended in the conversion to permanent structures when a mine is closed, in order to avoid breaches and potential environmental, human and material consequences (Centre d'expertise hydrique du Québec, 2019; Canadian Dam Association, 2013; Ministère du Développement durable, de l'Environnement et des Parcs, 2012; Aubertin et al., 2002, 1997; Vick, 2001). Importantly, there is currently no uniform methodological approach to factor climate change into the PMP and PMF calculations.

The frequency and intensity of extreme precipitation events, as well as average annual precipitation levels, are projected to increase in most regions across Canada (Zhang et al., 2019), increasing the risk of physical instability of waste containment structures (Bussière et al., 2017; Guthrie et al., 2010; Jakob and Lambert, 2009). Recovering spilled waste resulting from a dyke breach is difficult and expensive. For example, the tailings pond failure at the Aznalcollar mine in Spain in 1998 led to site reclamation costs estimated at about US$230 million (Eriksson and Adamek, 2000). In northern Canada, increasing temperatures are leading to permafrost degradation and increased depth of the annual thaw (active layer) (Derksen et al., 2019; Arzhanov and Mokhov, 2013; Zhang et al., 2008a, b). As a result, the integrity and stability of waste-retaining structures may be compromised. Increased thickness of the active layer can create problems in locating suitable construction sites for mining infrastructure; it should be noted that technologies for building on permafrost do exist and that relevant guidelines are well documented (Mine Environment Neutral Drainage, 2012; Doré and Zubeck, 2009; Andersland and Ladanyi, 2003).

7.5.3 Reclamation of mining sites

Reclamation of mining sites includes preventing contaminants such as acid mine drainage (AMD) from escaping into the environment (Blowes et al., 2003). This is possible by maintaining the long-term chemical stability of mine waste, as AMD results from the oxidation of sulphide minerals when they come into contact with water and atmospheric oxygen. Specific reclamation methods for preventing AMD are strongly influenced by climate conditions (*see* Box 7.1 and Case Story 7.6).

Box 7.1: Primary reclamation methods used in Canada

Reclamation of mine waste sites in Canada often uses covers to prevent acid mine drainage (AMD) (*see* Figure 7.9). In semi-arid to arid climates, such as the southern Prairie provinces and parts of south-central British Columbia, where the potential evaporation rate is high and annual rainfall low, reclamation systems aim to reduce the infiltration of precipitation into mine tailings that could generate contaminated drainage. In humid climates, such as in Ontario and southern Quebec, where the potential evaporation rate is relatively low with high annual precipitation, there is the additional task of creating barriers to control the migration of oxygen. In Arctic and sub-Arctic climates with continuous permafrost, controlling contaminated mine drainage usually consists of maintaining reactive waste at low temperatures by applying insulating covers that utilize the material's hydrothermal properties (applicable for average annual temperatures below -7°C; Holubec, 2004). Some techniques used in more temperate climates (e.g., flooding, waterproof covers) can also be applied to control AMD in cold regions (*see* Figure 7.9; Aubertin et al., 2016, 2015).

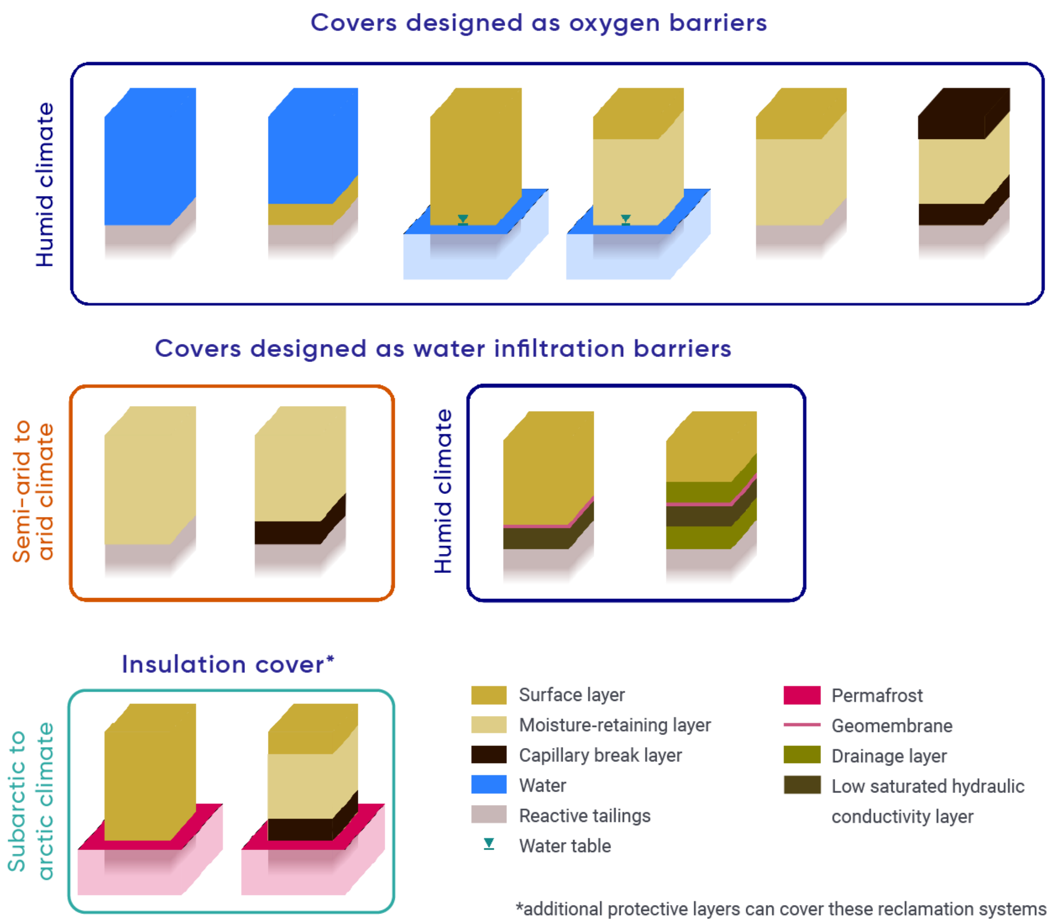

Figure 7.9: Primary reclamation methods used in Canada. Methods are designed to address critical issues that differ with climate regions. Source: Adapted from Bussière et al., 2017.

Case Story 7.6: Reclamation of the Lorraine, QC mine site

The Lorraine mine site in western Quebec was operational from 1964 to 1968. The tailings pond at this site covers an area of 15.5 hectares and was abandoned for about 30 years. During this period, significant acid mine drainage (AMD) was produced. To reduce the environmental impact of AMD, a reclamation project was undertaken in the summer of 1998 (Bussière et al., 2009; Nastev and Aubertin, 2000). Various issues were considered in selecting the most suitable design, including local climate, geochemical characteristics of the tailings, and available unconsolidated materials. The region receives significant annual precipitation (900–1,000 mm) and the evaporation rate is low (400–500 mm). In such a humid climate, controlling AMD generation focuses on reducing the migration of oxygen rather than using a water barrier (*see* Box 7.1). The reclamation approach recommended for this site was the construction of a cover with capillary barrier effects (CCBE) to limit the migration of oxygen into the reactive waste.

This site has been monitored since the CCBE construction. Measurements performed on the site show that after a transitional period of two years (1999–2000), the CCBE was effective in limiting oxygen migration (*see* Figure 7.10; Bussière et al., 2009; Dagenais et al., 2001). Oxygen fluxes measured are even lower than the goal targeted by the design. Numerical modelling incorporating climate change was carried out in order to assess recovery performance over the long term. The results show that, in this particular case, climate change will not have a significant impact on CCBE performance by 2100 (Hotton et al., 2019).

Figure 7.10: Evolution of the Lorraine, QC mine site reclaimed using a cover with capillary barrier effects. a) Before reclamation, b) after the 1998 reclamation and c) the site in 2007. Source: Adapted from Bussière et al., 2009.

The long-term effectiveness of reclamation systems is affected by many factors (Aubertin et al., 2015, 2002) related to the properties of the covering materials, the configuration and location of the containment area to be reclaimed, and climate. As the required life of reclamation structures is greater than 100 years, this is the stage of the mining cycle most likely to be severely impacted by climate change.

The main climate change risks during the reclamation of mining sites are reduced effectiveness of insulation covers, water infiltration barriers and oxygen barriers, and failure of retaining structures on sites undergoing reclamation (*see* Figure 7.11; Bussière et al., 2017; Lemmen et al., 2014). Direct climate change impacts of concern include: 1) higher temperatures that increase the depth of the active layer in sub-Arctic and Arctic regions, potentially resulting in the thaw of waste that could generate AMD; 2) an increase in extreme precipitation that could lead to the physical failure of dykes or other structures when employing reclamation methods such as water cover and elevated water table techniques; and 3) longer or more frequent droughts that could compromise the effectiveness of oxygen barriers that need high levels of saturation in the tailings and/or covers. Indirect climate change impacts, such as vegetation changes on revegetated sites affecting the water balance and the properties of the covering materials, can also positively or negatively impact the effectiveness of reclamation in both the short and long terms (Guittonny et al., 2018; Reinecke and Brodie, 2012).

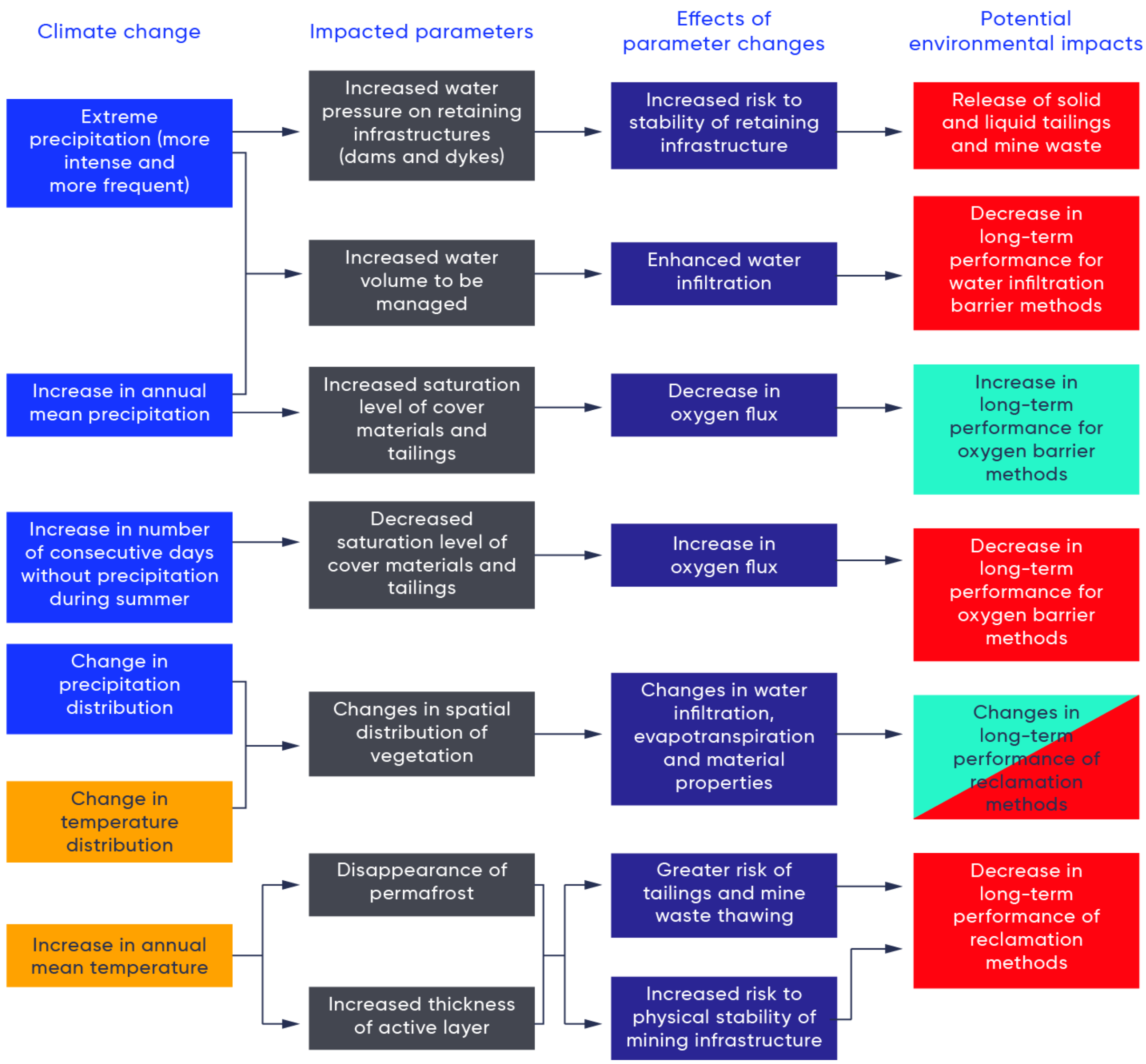

Figure 7.11: Summary of expected major climate changes and their implications for mine waste containment and reclamation structures.

7.5.4 Adaptation

Maintaining the stability of tailing containment structures currently represents a major challenge for the mining industry when following conventional containment methods (Aubertin et al., 2011; Azam and Li, 2010). Climate change will amplify these risks. Adaptation will involve considering approaches that reduce reliance on dykes to retain large volumes of water and tailings pulp. Thickened or filter-pressed tailings may be one viable option (Bussière, 2007). Co-disposal approaches of waste rock and tailings could also improve the mechanical resistance of containment structures for mine tailings (Aubertin et al., 2016, 2011; Wilson et al., 2003). The reuse of mine openings (open pits or underground voids) for the storage of waste rock and tailings can also help to reduce the problems of dyke instability (Aubertin et al., 2016, 2015). If mining companies choose to use conventional methods for mine waste storage, the effects of climate change must be integrated into risk management analysis during the design stage. Approaches with this aim are being developed in conjunction with the Mining Association of Canada and the Canadian Dam Association.

While most governments now require proof that climate change has been considered in the design of any reclamation project (e.g., Ministère du Développement durable, de l'Environnement et des Parcs, 2012 for Quebec), the lack of specific guidance on how to modify reclamation methods in the context of climate change remains a barrier to effective adaptation.

Specific tools and analysis are needed: for example, to inform the design of oxygen barriers, where an extended drought could lead to desaturation of the cover, increasing oxygen ingress (Bresson et al., 2018; Hotton et al., 2018). While studies in Quebec have simulated a period of approximately two months with no water intake (Éthier et al., 2018; Bussière et al., 2003), the choice of this period of time was not based on systematic analysis of meteorological data, and the probability of such an event occurring is unknown. Tools are needed that quantify the changing risk of extreme drought to be considered in the design of oxygen barriers. For sites located in cold climates, where increasing temperatures and precipitation will have a major impact on the performance of reclamation methods, the need for adaptation planning tools is particularly urgent.

Enhanced understanding of local impacts is also needed to inform the planting of perennial vegetation at reclamation sites. Over time, ecosystem changes driven by changing climate will result in species changes at the sites, but the impacts on the long-term effectiveness of reclamation systems are largely unknown (Guittonny et al., 2018). Monitoring the performance of such sites, to document whether such changes lead to deterioration or enhancement of the reclamation system, would provide important insights.

7.5.5 Moving forward

New approaches and tools that factor climate change into the planning, design, and risk management processes of mining activities provide a sound basis for the mining industry and governments to reduce the sector's vulnerability to climate change. While numerous studies have recommended that climate change be taken into account in mine waste management (e.g., Rousseau et al., 2014; Stratz and Hossain, 2014; Pearce et al., 2009; Aubertin et al., 2002), uncertainty in projecting changes, particularly extreme precipitation events (Mailhot et al., 2014), remains a barrier to action. Solutions require collaboration between mining engineers and climate services in developing updated or new methods and guidelines for assessing climate impacts that can be factored into the design of tailings containment structures and reclamation methods.

The longevity of tailings containment and reclamation structures increases their vulnerability to climate change. The physical and chemical stability of such structures is essential to avoid release of harmful contaminants into the environment. Tools and guidance are required to better enable designers to accommodate both changes in extreme weather caused by climate change, and slow-onset changes such as permafrost degradation, and to develop climate-resilient reclamation methods. In some cases, it is possible that, for a given site, a "best" solution for current climate conditions may not be the optimum solution for future conditions. Better designed tailings containment and reclamation structures at active and closed mine sites can significantly reduce the risk of environmental contamination over the long term. In the case of older infrastructure, it would be advisable to conduct analyses to ensure that these facilities will be able to withstand future conditions. If not, remedial measures will have to be implemented to maintain the integrity of the structures over the long term.

7.6 Each link of the energy value chain can be vulnerable to climate change

Changing climate affects energy demand and the full energy value chain, from exploration and production through to transmission and distribution. Climate risks can be integrated into current business planning by considering co-benefits, no-regret options and incremental approaches. Climate resilience needs to be a key consideration in converting to low-carbon energy systems.

Warming climate increases the demand for cooling in summer and decreases the demand for heating in winter. Energy supply is sensitive to a wide range of climate impacts, including changes in permafrost, ice cover, sea level, wave regimes, precipitation patterns, river flows and extreme weather events, such as hurricanes and ice storms. These impacts can all disrupt the energy value chain, with significant economic and social consequences. The use of climate risk screening tools can help to embed adaptation within current business planning practices and to identify opportunities for introducing adaptation measures at cost-effective times (e.g., during maintenance, upgrades and retrofits). As significant investments are made to convert to low-carbon energy systems over the next few decades, it will be important to ensure that climate resilience is considered in infrastructure design.

7.6.1 Introduction

Energy is an important component of the Canadian economy, accounting for almost 10% of gross domestic product (GDP). Energy systems are the backbone of critical services, such as transportation, communication, health systems, drinking water and wastewater, as well as businesses and households. As such, their reliability is of paramount importance to economic activity and human well-being in Canada. Energy assets and operations have always been exposed to highly variable and extreme climate conditions, and were built to perform well under these conditions. Nonetheless, they were designed based on historical climate norms, which raises concern about their resilience in the face of ongoing changes in climate. Observed and projected climate changes that significantly affect the energy sector are described in Bush and Lemmen (2019), including changes in temperature and precipitation extremes (Zhang et al., 2019), permafrost, snow and sea ice (Derksen et al., 2019), streamflow (Bonsal et al., 2019) and ocean climate (Greenan et al., 2019a). Energy sector vulnerabilities to climate are highlighted by recent extreme events, including the 2016 Fort McMurray (Horse River) wildfire that devastated the community and caused substantial reductions in oil sands production, with an estimated loss of approximately 47 million barrels, costing producers 1.4 billion dollars in lost revenues (*see* Case Study 7.1; National Energy Board, 2016; Antunes et al., 2016).

Climate change also has direct and indirect impacts on energy demand. Warmer winters reduce fossil fuel and electricity demand for heating (Mantle314, 2019), while the increasing number of hot days in summer increase electricity demand for cooling (Ortiz et al., 2018; Jaglom et al., 2014). Indirect impacts are associated with societal and government responses to reduce greenhouse gas emissions, and these responses have differing impacts on renewable and non-renewable energy sources (International Energy Agency, 2016a).

Previous assessments of climate change impacts and adaptation highlight the diversity of the Canadian energy sector, noting that most available research focuses on hydroelectricity generation and electricity distribution (Lemmen et al., 2014). Key risks identified include impacts of extreme weather on critical infrastructure, and a potential mismatch between reduced hydroelectricity production and increased electricity demand during heat waves. Smart grid technologies and urban design measures that reduce heat island effects were noted as examples of adaptation measures (Lemmen et al., 2014). Knowledge gaps identified included the limited amount of research on the impacts of climate change on renewable energy supplies other than hydroelectricity. Environmental assessment and risk disclosure were identified as emerging drivers of adaptation action in the sector (*see* Climate Disclosure, Litigation and Finance chapter; Lemmen et al., 2014).

7.6.2 Risks to energy production and transmission

The impacts of a changing climate will vary between energy type and region, and may occur at different time horizons. The Canadian oil and gas sector fuels most transportation and accounts for 10% of Canada's electricity generation (Natural Resources Canada, 2018). Oil and gas exploration, extraction, production and delivery will be affected by climate change (Mantle314, 2019; Cruz and Krausmann, 2013). Pipelines, roads and buildings are affected by permafrost degradation, slope failures and flooding. In northern regions, thawing permafrost and reduced availability of stable ice roads affect transportation and require changes in schedules. River ice breakup will happen earlier in the year and ice jam flooding may occur more frequently. Sea-level rise will change flood risks and increase coastal erosion. A large water demand for energy production, including for oil sands, may pose a risk as overall water availability declines in some areas and droughts may intensify (Bonsal et al., 2019). Offshore activities may benefit from increased access to resources in the Arctic due to reduced sea ice, but will still face significant risks from ice in northern regions and increased impacts from waves elsewhere (Mantle314, 2019; Stantec Consulting Ltd., 2012). While not directly related to production, carbon capture and storage (CCS) technology is critical to the oil and gas sector's transformation to low-carbon systems. Indeed, the World Energy Council stated that "global warming is unlikely to be kept under 2°C without introduction and widespread adoption of CCS, and the cost of mitigation would be higher in the absence of CCS" (World Energy Council et al., 2014, p. 12). However, CCS technologies are water-intensive, using almost double the volume of water compared to non-carbon capture and storage plants, making them vulnerable to climate-related changes in fresh water availability (International Energy Agency, 2015).

Nuclear and fossil fuel thermal generation facilities depend on sufficient cooling water and may face reduced cooling efficiency due to higher water temperatures or contamination of cooling water intake (e.g., from algae, zebra mussels or ice particles during freeze/thaw cycles) (Braun and Fournier, 2016; Canadian Electricity Association, 2016). Maintenance schedules for nuclear facilities may be impacted by increased ambient temperatures, as temperature affects the number of workers allowed in vaults. Extreme impacts are exemplified by the shutdown of nuclear power plants in France due to lack of cooling water during the 2003 heat wave (Kopytko and Perkins, 2011).

Hydropower accounts for 59% of Canada's electricity generation (Natural Resources Canada, 2018). As this is a renewable energy source depending directly on climate conditions, hydropower production is impacted by changes in temperature, precipitation and snow cover. Shorter winters will result in earlier spring floods with a smaller contribution from melting snow. Winter flows are expected to be higher, and late summer flows may be reduced in many parts of Canada (Bonsal et al., 2019). At higher latitudes, where higher precipitation is not offset by increased evapotranspiration, generation potential may increase. However, with changes in rainfall frequency and intensity, risks to infrastructure may also increase and changes to water management would be needed to minimize losses. The high flexibility provided by the storage capacity of hydropower operations means that they can play a key role in transitioning to a low-carbon energy system, providing stability for electricity grids that integrate more volatile renewables such as wind and solar (International Energy Agency, 2018). A review of 200 projects in the energy sector suggests that hydropower is the most advanced subsector with respect to climate change adaptation (Braun and Fournier, 2016).

Non-hydro renewable energy, which includes wind, solar and biomass, is becoming increasingly important in Canada's energy mix, a trend that will continue in the future (*see* Figure 7.12; National Energy Board, 2018, 2017). Wind generation will generally be reduced from lower density air at higher temperatures. A 5°C increase in air temperature leads to a decrease in air density of 1–2%, with a proportionate decline in energy density affecting power production (Pryor and Barthelmie, 2010). However, wind generation may benefit from more sustained and higher winds. Fast market growth of renewable wind power (*see* Figure 7.12) reflects the influence of a larger share of renewable energy sources being integrated into the economy in response to climate change. Solar capacity is increasing even more rapidly than wind, and is expected to triple by 2040 (*see* Figure 7.12; National Energy Board, 2018, 2017). While there are concerns that an increase in cloudiness due to changing weather patterns and extreme weather events could affect solar energy generation (World Energy Council et al., 2014), the significance of these impacts is regionally dependent. More research is needed in Canada.

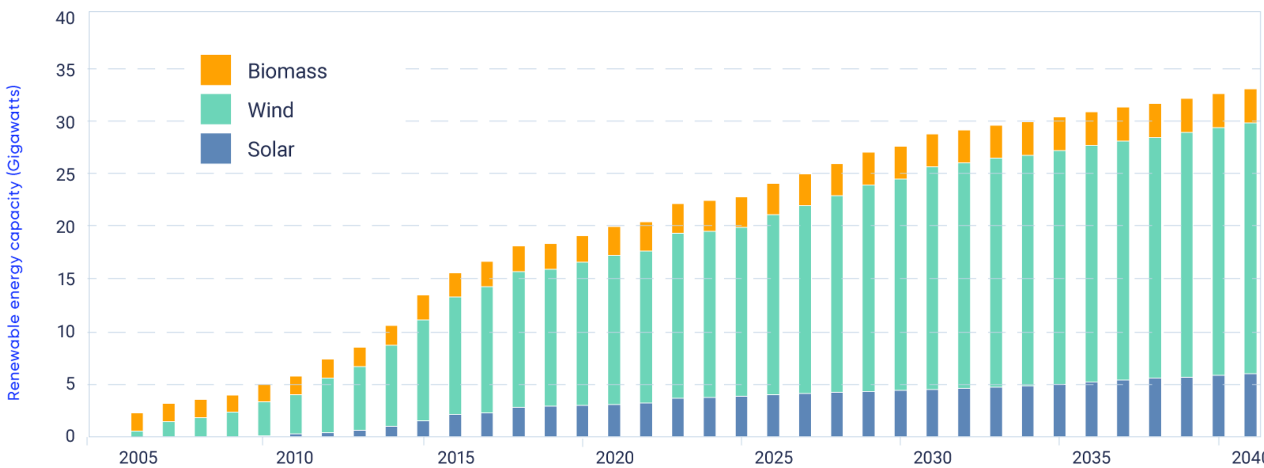

Figure 7.12: Observed and projected changes in non-hydro renewable energy capacity in Canada between 2005 and 2040 under the National Energy Board reference case scenario. Higher rates of growth are projected under a technology scenario (NEB, 2018). Source: Adapted from National Energy Board, 2018.

The electricity transmission and distribution sector will be affected by many factors, including the following: 1) increased temperatures, which can increase line resistance by approximately 0.4% per 1°C rise and decrease line load capacity by 0.5 to 1% per 1°C rise; 2) thermal expansion of power lines, which affects safety line clearances (a 1°C rise can result in 4.5 cm of sag); 3) extreme precipitation events that increase the risk of flooding of underground assets; and 4) high winds and gusts that can cause line damage (Asian Development Bank, 2013, 2012).

7.6.3 Adaptation

There are several examples of the energy industry adapting to changing climate conditions in Canada and around the world. Western Power Distribution in the UK studied the impact of higher ambient temperatures on its grid and developed a "low-regret" approach to adapt to an increase of their line rating by 5°C. To compensate for projected increased sag of the lines, they have started to gradually replace the poles in the course of normal maintenance (Western Power Distribution, 2011). Hydro-Québec has adopted a method to improve its energy demand forecasting by applying a climate-model derived adjustment factor to the historical temperature record prior to running the forecast model (Braun, 2016). A similar approach to improve flow forecasts has been adopted by Iceland's National Power provider Landsvirkjun, which has adjusted its streamflow record based on climate projections (*see* Case Story 7.7; Fournier, 2016).

Case Story 7.7: Opportunities for increased hydropower production in Iceland

Electricity and heating in Iceland are derived entirely from renewable sources (hydro and geothermal). Warming temperatures and increased precipitation result in increased glacier melt, runoff and generation capacity. However, the design of the current system in Iceland will only be capable of utilizing 30% of the projected additional runoff. Maximizing the opportunities presented by climate change will require new investments to increase storage in the system (*see* Figure 7.13; Sveinsson, 2015). Similar planning approaches may be appropriate in northern Canada where runoff is projected to increase as a result of climate change (Bonsal et al., 2019).

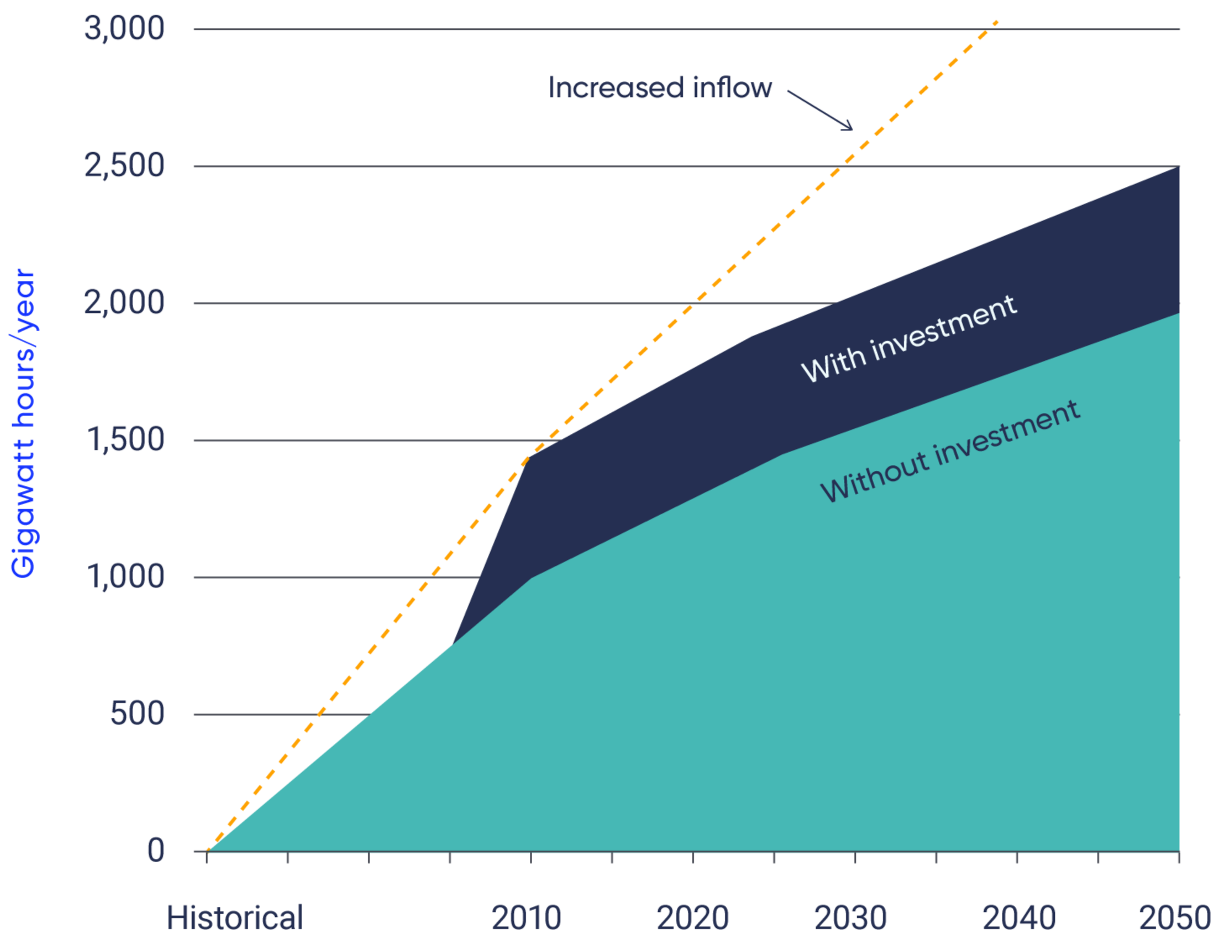

Figure 7.13: Potential increases in hydropower production in Iceland as a result of climate-induced increases in runoff and additional investments in infrastructure. Source: Adapted from Sveinsson, 2015.

New technologies are a key tool for climate change adaptation in the energy sector. The International Energy Agency's Sixth Forum on the Climate-Energy Security Nexus identified "technology innovation" as a priority area to advance energy sector resilience to climate change in North America (International Energy Agency, 2016b). While decentralized renewable energy technologies have been driven largely by demand for low-emitting energy sources, they also provide redundancy that can create sub-systems for generating and distributing energy in the event that other parts of the grid are disrupted (American Council on Renewable Energy, 2018; IISD, 2017; U.S. Department of Energy, 2016; International Energy Agency, 2015). Smart grid technologies, including renewable energy generation, smart meters, smart appliances, and automatic power production have been proven to improve recovery from extreme weather, such as in the US with Hurricane Irene (2011) and Hurricane Sandy (2012) (IISD, 2017; Executive Office of the President, 2013). For thermal generation, new dry-cooling technologies are being implemented to reduce the vulnerability to changing temperatures and diminish dependency on cooling water sources (Braun and Fournier, 2016).

7.6.4 Moving forward

Increased awareness is a critical first step in developing a climate-resilient energy sector that can ensure future energy security and reliable service for Canadians. Detailed case studies of projected impacts and actual or proposed business responses are a valuable tool for building such awareness (Braun and Fournier, 2016). Responses should be feasible, economically sound, and able to be implemented in adequate time frames. Cost-effective and beneficial responses can be built into existing business operations—for example, by addressing climate change as an integral part of environmental impact assessments, as is required for projects undergoing a federal impact assessment (Environment and Climate Change Canada, 2020).

Proactive energy providers in Canada and abroad have established in-house climate expertise and climate change committees. These committees collaborate with researchers and climate change centres to understand, produce and use climate data for establishing operational thresholds that are sensitive to climate. Engaging asset managers can be an important component of a holistic, integrated risk-based approach for energy planning, as is strong monitoring and evaluation. Sharing adaptation case studies between companies is another way to advance climate resilience in the energy sector.

7.7 Extreme weather events impact transportation, disrupting supply chains

Road, rail, marine and air transportation in Canada are vulnerable to extreme weather events and slow-onset climate change, with major disruptions having significant economic and social impacts. To fully assess these impacts, linkages between transportation systems, and between transportation modes and a wide range of other economic sectors, need to be accounted for. Coordinating adaptation responses across jurisdictions and sectors will benefit transportation asset owners, operators and those dependent on vulnerable supply chains and corridors.

Canada relies on efficient, safe and reliable transportation infrastructure and operations that enable the movement of goods, services and people across the country. Current climate risk assessment and adaptation initiatives in the transportation sector tend to focus on individual, direct climate impacts associated with air, road, rail or marine infrastructure and other assets. This approach underestimates the potential cascading risks and impacts from surrounding assets or networks, and vice versa. Examining how various elements of transportation are dependent upon each other, and how transportation is linked to a wide range of other sectors, can help to identify opportunities for collaboration and cost efficiencies, and can prevent situations in which actions taken to reduce individual or specific risks inadvertently increase the climate vulnerability of others.

7.7.1 Introduction

A well-functioning transportation sector connects people and communities, products, resources and services to domestic and international markets (Palko, 2017). In Canada, responsibilities for transportation are dispersed across various levels of government, with private-sector stakeholders playing an important role as owners, operators and managers of infrastructure and assets, including railway infrastructure, vehicles, ships and aircraft (Andrey and Palko, 2017). Canada's transportation infrastructure is concentrated mainly in the southern portion of the country, where most of the trade and transportation movements occur (*see* Figure 7.14). However, northern transportation systems are particularly sensitive to climate change, and are already impacted by thawing permafrost, reduced river, lake and sea ice cover, and increases in coastal erosion and storm surge flooding (Palko, 2017; Hori et al., 2017).

National Airport System

National Highway System

Canada Port Authorities

National Railway Network

Figure 7.14: Maps of Canada's national transportation systems, showing the National Airport System, the National Highway System, Canada Port Authorities and the National Railway Network. Source: Adapted from Transport Canada, 2017.

A comprehensive, regional-based report of climate change impacts and adaptation actions in Canada was released in 2017 (Palko and Lemmen, 2017). Key findings include:

- Canada's transportation infrastructure is vulnerable to damage and disruptions from a changing climate and extreme weather, and this can pose risks to other sectors of the economy;
- Northern transportation systems are experiencing some of the greatest impacts from warming, and temperatures in the North will continue to increase at a faster rate than in any other region of Canada; and
- While reactive approaches to managing climate risks remain common in Canada's transportation sector, there are examples from all regions and transportation modes of adaptation actions being taken in anticipation of future climate conditions.

This section supplements the report, *Climate Risks and Adaptation Practices for the Canadian Transportation Sector* (2017), by examining the interconnections that exist within intermodal transportation systems and across a wide range of sectors. It draws upon Canadian and international literature, and focuses primarily on physical infrastructure.

7.7.2 Climate impacts on transportation systems

Impacts of extreme weather events and climate change are already affecting transportation infrastructure, operations, systems and services across all modes in all regions of Canada (Palko, 2017); it should be noted that climate change has already increased the likelihood of some types of extreme weather events (Zhang et al., 2019). In some cases, these impacts have resulted in travel disruptions and unsafe conditions, affecting the movement of both freight and people, and leading to increased operating costs, reduced revenues or compensation for service disruptions.

Extreme weather events can incur large costs and accelerate the deterioration of transportation infrastructure, shortening its lifespan (Boyle et al., 2013). For example, a torrential downpour in Toronto in 2013 resulted in flooding that caused road closures, flight delays and cancellations, and stranded 1,400 train commuters. Damages were estimated to be $999.5 million (Amec Foster Wheeler Environment Infrastructure, 2017). That same year, flooding in southern Alberta caused $6 billion in damages, washing out 1,000 km of roads and destroying several hundred bridges and culverts (Andrey and Palko, 2017). In 2017 and 2018, the Churchill rail line was closed for 18 months (CTV, 2018) due to the cumulative effects of flooding and permafrost degradation beneath the railway line. Without a viable alternative mode of transportation to bring supplies in and ship goods out, living expenses escalated and access to essential services, including medical services located in southern communities, were compromised (Globe and Mail, 2018).

7.7.3 Understanding interdependencies

Infrastructure sectors and systems, including transportation, energy, telecommunications, water supply, wastewater treatment, solid waste management, and buildings, are "highly interdependent on each other, containing multiple connections, feedback and feed-forward paths and intricate branching" (Sudhalkar et al., 2017, p. 3).

Examples of critical interdependencies in transportation systems include situations where two sectors are essential to one another (e.g., transportation and energy), and where technology serves to strengthen connections between infrastructure, such as railway signals and traffic control systems being controlled by computer systems that depend on electrical power grids (Sudhalkar et al., 2017). Infrastructure networks containing one or more of these features "are at a higher risk of failure from external shocks or stresses, including climate hazards" (Sudhalkar et al., 2017, p. 3). Climate change risk assessments that do not address such interconnections could lead to the miscalculation of risks (Dawson, 2015).

Within the Canadian transportation sector, transportation modes (e.g., rail, marine, aviation and trucking) are often interconnected (intermodal) within supply chains and across transportation gateways and corridors. Port infrastructure and facilities, for example, form a central hub for transportation, logistics and supply chains, and are key convergence points for marine, rail and road infrastructure to facilitate movements of domestic and foreign goods (Becker et al., 2018).

Disruptions and delays in domestic and international supply chains, including those caused by weather events, can spread across networks with negative social and economic impacts (Becker et al., 2018; Allen et al., 2016; Zorn et al., 2016). In this way, vulnerabilities in one mode of transportation or sector can cascade to others.

7.7.4 Adaptation

Transportation asset owners and operators across Canada are undertaking actions to consider their climate risks and strengthen resiliency, often independently (Kwiatkowski, 2017). The distinct mandates, priorities, commercial sensitivities and resources of the many players within the sector create governance challenges and barriers to action (Sudhalkar et al., 2017). In the absence of holistic adaptation strategies, individual investments to address adaptation will be limited in effectiveness and could have unexpected and unintended negative consequences on neighbouring or interdependent assets and systems (Kwiatkowski, 2017). For example, the City of Toronto undertook a high-level climate risk assessment and interdependencies exercise for critical infrastructure and found that stakeholders had insufficient knowledge about the impacts of their activities on other interdependent systems, and that there was a need to implement roles and responsibilities to tackle joint risks (Sudhalkar et al., 2017).

Challenges for adaptation arise from many sources, including the fact that many transportation assets have long life-cycles, requiring lengthy planning and design, whereas technological development and replacement in areas such as information and communication technologies occur very quickly, leading to mismatched planning horizons and potential timing challenges (Man, 2013; Dewar and Wachs, 2008; Finley and Schuchard, nd). Opportunities arise when transportation planning is able to overcome such challenges and facilitate broad collaboration and engagement across sectors and jurisdictions. These include the following: early identification of multiple benefits and potential solutions (Man, 2013), which can be particularly important in areas of shared land use (Department of Environment, Food and Rural Affairs, 2011); improved understanding of interdependencies amongst multiple infrastructure owners; and increased innovation and efficiency across the supply chain (Dubois et al., 2011).

Tools have been developed to help planners consider risks associated with interdependencies. An example developed in Australia enables a systems-wide analysis of climate risks to organizations, as well as upstream and downstream interdependencies (Cross Dependency Initiative, 2019). Outcomes can demonstrate which 'third-party risks" can affect an organization's system, as well as the consequences of their own failure risks to other critical infrastructure, and can facilitate collaborative adaptation measures (Cross Dependency Initiative, 2019).

Case Story 7.8 provides an example of how stakeholders have come together to collectively explore interdependencies with transportation, as well as climate change risks to infrastructure and operations, in Surrey, BC.

Case Story 7.8: Addressing increasing flood risk in Surrey, BC

Flood controls in Surrey, British Columbia, were initially developed in the late 1800s. Projected sea-level rise increases the risks of a major flood event, affecting not only residents of Surrey but also the regional and national economy (City of Surrey, 2018). The flood hazards include inundation of a network of regional infrastructure (including water and sewer lines, roadways and highways servicing 200,000 daily vehicle trips across the floodplain), and green infrastructure delivering critical ecosystem services (such as salt marshes and wetlands). The nationally significant economic activities exposed to coastal flood risk include:

- Transportation corridors servicing nearly 10 million annual passenger crossings between Canada and the USA (Bureau of Transportation Statistics, 2018);
- $3 billion in annual goods movement along the Roberts Bank Railway Corridor and the BNSF Railway (connecting Port of Vancouver Facilities with Canada and the USA, respectively); and
- the primary BC Hydro connection to the Bonneville Power Authority in Washington State.

To manage increasing climate risks, the City of Surrey adopted a bottom-up approach involving multiple asset owners across infrastructure sectors to collaboratively assess the shared risk of coastal flooding (Associated Engineering Limited, 2018). Conversations between asset owners, operators and emergency responders servicing the area flourished as a result of a study tour that allowed participants to see and hear about key infrastructure interdependencies. The infrastructure is complex, and the various organizations face different operational challenges and balance them with long-term capital upgrades in different ways, based on their risk tolerance and available resources.

A shared understanding of climate risk was developed by applying Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol (PIEVC, n.d.). This included a triple-bottom-line assessment to identify the social, environmental and economic drivers that are common amongst the owners. Given the distributed benefit of conducting the assessment, funding through the Municipalities for Climate Innovation Program was critical to foster early collaboration that might otherwise have been limited if cost sharing negotiations were required. Although influences on decision making varied across organizations, positive public perception was a key concern for many asset owners (Associated Engineering Limited, 2018).

The next step will be to develop a long-term framework for asset owners to follow to manage the increasing risk of coastal flooding due to sea-level rise, and to better coordinate investments through infrastructure renewal opportunities and develop win-win-win solutions (Associated Engineering Limited, 2018). Key aspects of the framework will be to formalize appropriate pathways for resolving the geographic and physical interdependencies of each infrastructure owner, and monitoring progress in managing climate risk over time.

In some cases, only a single asset owner is involved. For example, in the City of Surrey, the Engineering and Parks, Recreation and Culture departments are working together to adapt to rising water levels, which are impacting a critical transportation route and parkland. Interdependencies provide an opportunity to access the federal Disaster Mitigation and Adaptation Fund, whereas addressing individual assets in isolation does not meet the federal funding requirements. A cross-departmental adaptation approach has been developed that integrates a flood control structure with a bridge replacement and a riverfront park. Coordinating these actions will reduce overall capital costs, increase cost sharing, accelerate adaptation and increase public support by providing immediate community benefits, in addition to reducing long-term risks.

Asset management and renewal also provide an opportunity to proactively reduce risk exposure. Surrey is using standard renewal cycles to adapt key infrastructure to address projected climate impacts over their design life. For example, infrastructure in Mud Bay (*see* Figure 7.15) is serviced by a drainage pump station that is nearing the end of its functional life, and the replacement station has been designed to be resilient to multiple hazards, including higher water levels, seismic events and ground subsidence. In addition, the flood control dyke will be significantly raised. To adapt to sea-level rise, geographic and physical interdependencies need to be addressed, including the following (*see* Figure 7.15):

1. A provincial overpass that needs to be raised to maintain the approach grade of the railway and to preserve the railway clearance envelope; and
2. The class 1, federally regulated American railway that requires raising to accommodate a higher dyke crest designed to protect infrastructure and avoid a weak point.

The end result is that adaptations to the transportation system were not simply defined by direct physical risks to roads and the railway, but were achieved through a coordinated approach to enhance resilience across multiple sectors. This approach enabled actions that meet the needs of each sector as established through a participatory and collaborative process.

Figure 7.15: Interconnected infrastructure in Mud Bay, Surrey, BC highlighting the need for coordinated approaches in addressing risks presented by sea-level rise and other hazards. Source: Adapted from the City of Surrey, 2018.

7.7.5 Moving forward

Changing climate and extreme weather continue to pose challenges to Canada's transportation sector. A range of interdependencies exists within the sector (between transportation modes) and across sectors. Without consideration of interdependencies and interrelated risks, individual investments to improve climate resilience will be limited in effectiveness or will result in unexpected or unintended consequences. Collaborative approaches can help asset owners and operators better understand the range of potential risks and identify adaptation solutions that respond to and cut across multiple risk areas. There are practical examples, including the City of Surrey (*see* Case Story 7.8), that demonstrate the multiple benefits that can be produced through such partnerships, trust and more informed planning.

7.8 Climate change is leading to transformational changes in tourism

All tourism destinations need to adapt to climate change impacts on tourism assets and altered competitiveness within the highly interconnected tourism economy. While Canadian tourism competitiveness is expected to increase under climate change, the specific market and regional implications of this change for national competitiveness remain under-researched. Winter and northern tourism and recreation are particularly sensitive to climate variability, and transformational changes in ski, snowmobile and Arctic cruise tourism are expected.

Tourism is Canada's largest service sector. Climate change is influencing Canadian tourism operations, investment and travel patterns, requiring adaptation by all tourism destinations. Many risks and some opportunities will progressively increase over this century, causing geographical shifts to enable seasonal and nature-based tourism markets to thrive. Earliest impacts have been visible in winter tourism markets, where declining snow and ice conditions are affecting the viability of multi-billion dollar tourism industries across Canada, much of which is concentrated in small and rural communities. The ski industry has invested hundreds of millions of dollars in snowmaking, providing substantial capacity to adapt to future warming and reduced natural snow fall in some locations. Higher warming scenarios will exceed the technical limits of snowmaking adaptation in many locations. The snowmobile industry is highly vulnerable to the same changes because snowmaking is not technically or economically viable for thousands of kilometres of trails, and ice crossings will become increasingly unsafe. Melting glaciers and reduced sea ice are altering tourist attractions from the Rocky Mountain national parks to polar bear and Arctic cruise tourism in the Canadian Arctic Archipelago. Tourists, tourism operators and destination communities are adapting to these diverse climate risks and opportunities, sometimes with unintended consequences for non-tourism government agencies (e.g., search and rescue), communities (e.g., overtourism) and visitor experience.

7.8.1 Introduction

Climate change poses diverse risks and opportunities to domestic and international tourism across Canada (Scott et al., 2020; Hewer and Gough, 2018; Scott et al., 2012). Climate change is already influencing tourism operations, investment, and travel patterns so that all tourism destinations will need to adapt to impacts on local tourism assets, as well as to altered competitiveness within the highly interconnected international tourism economy (Scott et al., 2020, 2016). Globally, high emission pathways are widely considered to be incompatible with projected tourism growth (Scott et al., 2019; IPCC, 2018). Based on the various analyses of the multiple impacts of climate change on the tourism sector, Canada's international tourism competitiveness is expected to improve (Scott et al., 2019; Roson and Sartori, 2016; OECD, 2015). The impacts of changing seasonality, landscapes (e.g., beaches, water levels), biodiversity, extreme events (e.g., heat waves, forest fires) and transnational markets have far-reaching, yet under-researched, implications for tourism development and competitiveness, travel patterns and livelihoods.

An overview of broad climate impacts and adaptation actions in the Canadian tourism industry was provided in Kovacs and Thistlethwaite (2014), including a discussion of implications for the parks system, warm- and cold-weather recreation, and nature-based tourism. While noting examples of advanced adaptation planning efforts, the overview concluded that the level of preparedness across the tourism sector to deal with climate change was low, which is consistent with assessments of the sector's preparedness globally (Becken et al., 2020; Scott et al., 2016). Climate change also presents emerging opportunities for some tourism markets, who would also need to adapt in order to realize potential economic benefits, sustain tourism assets and maintain visitor experience.

This section builds on the findings of Kovacs and Thistlethwaite (2014) by focusing on snow- and ice-dependent markets like ski, snowmobile and Arctic cruise tourism, because these are where the impacts of changing climate are being experienced first and where adaptation by the tourism industry and investors is ongoing. Details of observed and projected changes in snow and ice cover (including sea, lake and river ice, glaciers and permafrost) are presented in Chapter 5 of *Canada's Changing Climate Report* (Derksen et al., 2019).

7.8.2 Winter sports tourism

The ski industry of North America has invested hundreds of millions of dollars in snowmaking over the last 30 years to reduce its climate sensitivity. While average winter temperatures have continued to rise, the length of ski seasons increased throughout the 1980s, 1990s and 2000s in all five regional ski markets in the United States (Scott and Steiger, 2013). Only in the 2010s has this trend reversed, suggesting that advanced snowmaking capacity may no longer be able to offset winter warming. Recent record warm winters that are analogues for normal future winter conditions provide important insight into how the ski industry and ski tourists adapt. During the record warm winter of 2011–2012, the Ontario ski market experienced an average decrease in the ski season length (-17%) and in skiable terrain (-9%), reduced snow quality (-46% days with packed powder), fewer snowmaking days (-18%) and increased early season snowmaking (+300% in December), as well as a 10% decrease in overall skier visits, when compared to a climatically normal winter for the 1981–2010 period (Rutty et al., 2017). Similar impacts on season length and visitation have been observed in the Quebec market, with skier visits reduced by 12.5% in the record warm winter of 2015–2016 (Association des Stations de Ski du Québec, 2016).

Differences in exposure to climate change risk among ski destinations have important implications for intra- and inter-regional market competitiveness and geographical shifts in ski tourism. A comparison of climate change impacts on the ski seasons in ski areas in Ontario, Quebec and the Northeastern United States revealed different futures for these regional markets for the 2050s and 2080s (*see* Figure 7.16). Ski areas in Quebec and high-elevation locations in Vermont and New Hampshire are more climate-resilient than those in Ontario and lower-elevation/lower-latitude locations in the US Northeast (Scott et al., 2020). Analysis of three ski areas in Quebec projected almost identical season losses of 10 to 20 days in the 2050s, and an expected 10% reduction in skier visits (Da Silva et al., 2019). Important information gaps remain, such as for Canada's largest ski tourism markets (British Columbia and Alberta) and regarding the implications of differential impacts on market dynamics, tourism and community-level employment, development pressures and vacation real estate values (Scott et al., 2017; Rutty et al., 2015).

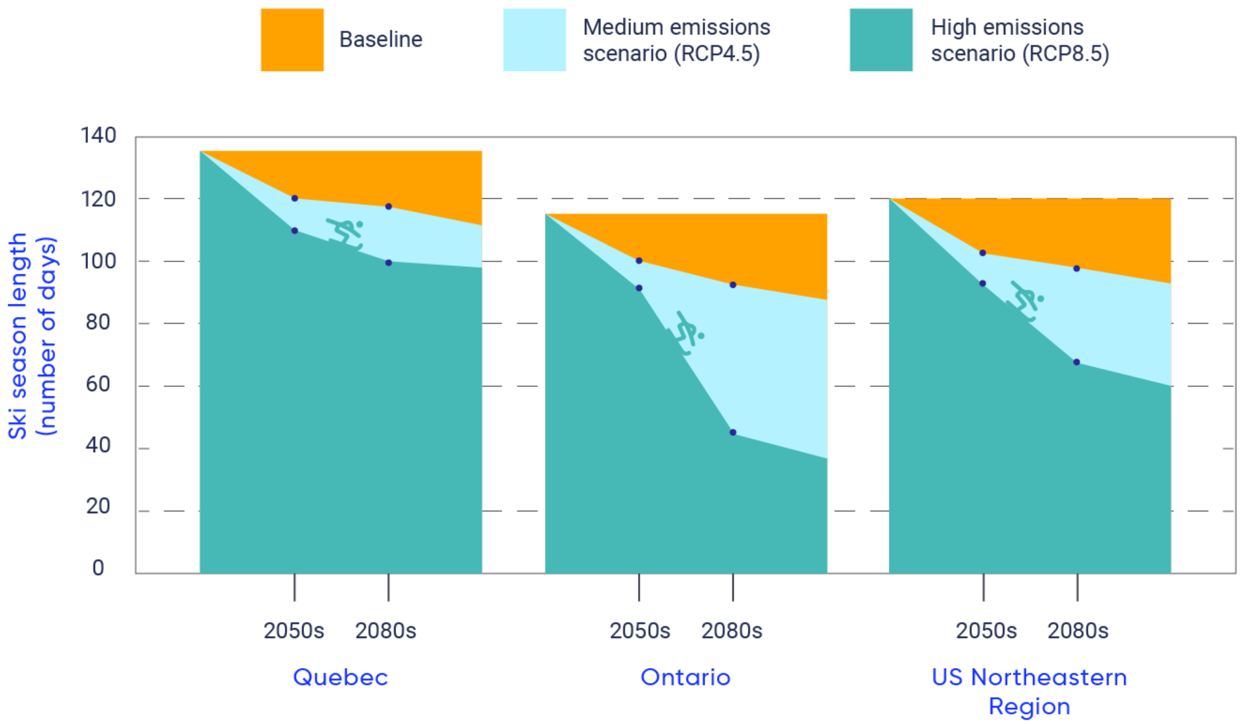

Figure 7.16: Inter-comparison of changes to ski season length in Ontario, Quebec and New England markets with advanced snowmaking capacity under medium emissions (RCP4.5) and high emissions (RCP8.5) scenarios for the 2050s and 2080s. Baseline refers to the period 1981–2010. Source: Adapted from Scott et al., 2020.

Studies of the impact of ongoing and projected reductions in winter season snow on the snowmobile industry of North America show that while riders are adapting to changing conditions, continued deterioration of the season length will result in loss of this tourism market in many regions of the US and Canada (Perry et al., 2018; Hatchett and Eisen, 2018; Tercek and Rodman, 2016; McBoyle et al., 2007). Under the high-emissions scenario projected for the 2050s, a reliable snowmobiling season will be largely eliminated in regions of Ontario and Quebec with the densest network of snowmobile trails (McBoyle et al., 2007). A 20% decline in registered snowmobiles in Canada from 1995 to 2015 (International Snowmobile Manufacturers Association data) may signify a climate adaptation by individuals that will induce changes in this tourism marketplace. Bombardier Recreational Products (2017) advised investors that global climate change might impact future snowmobile sales to a greater extent than previously anticipated. A shift to all-terrain vehicles is not thought to be a feasible adaptation strategy, as these vehicles tend to be more impactful on trail surfaces, preventing shared trail networks and access by other users to parks and farmlands (Perry et al., 2018; McBoyle et al., 2007).

7.8.3. Arctic cruise tourism

Declining summer sea ice cover has allowed greater marine access to the majestic land, seascapes and cultures of the Canadian Arctic (*see* Northern Canada chapter). This has opened up access to areas and communities that were previously inaccessible to tourist vessels. Tourism operators and tourists have been quick to adapt to these new opportunities, with strong growth in commercial (cruise ships) and non-commercial (private yachts) tourism vessel traffic since the late 2000s (Dawson et al., 2018; Johnston et al., 2017). Although tourism development is considered highly strategic by pan-Arctic governments (Dawson et al., 2017), there are concerns related to infrastructure needed for hosting the growing tourist numbers, environmental impacts, uneven economic opportunities, negative local social and cultural impacts, and limited search and rescue capacity (Dawson et al., 2018; Stewart et al., 2011). Limited hydrographic charts and changing ice conditions increase the risk of a high-impact cruise ship incident (Dawson et al., 2016). Even relatively minor incidents can be associated with high costs (*see* Case Story 7.9). Integrated multi-sector adaptation is essential to respond to these challenges and support sustainable tourism in the Canadian Arctic.

Case Story 7.9: The costs of increased tourism ship traffic in the Canadian Arctic

Unregulated cruise ship and pleasure craft (yacht) tourism traffic has been growing steadily in the Canadian Arctic as a result of changing ice conditions (*see* Figure 7.17; Dawson et al., 2018). This response by tourism operators and tourists has raised concerns over the potential for search and rescue capacity to respond to a high-risk incident, such as the sinking of a cruise ship. The grounding of the Akademik Ioffe near Kugaaruk, Nunavut in August 2018 revealed the high costs of search and rescue for even a minor incident involving a tourism vessel. The Canadian Forces spent over $500,000 to provide assistance, while the cost of two icebreakers that also responded were not reported by the Canadian Coast Guard (Toth, 2018). Investment in improved navigation charts in common shipping routes and insurance requirements to indemnify search and rescue costs have been identified as possible adaptation responses to reduce safety and financial risks.

Figure 7.17: Cruise ship Hanseatic arriving in Pond Inlet, NU, ca. 2005. Photo courtesy of Emma J. Stewart, Lincoln University.

7.8.4 "Last chance" tourism

Some evidence supports the emergence of a travel trend of "last chance" tourism. This refers to travel by tourists to visit sites before their attractions vanish or are irrevocably degraded, or to witness the impact of climate-induced landscape changes, such as rapidly melting glaciers or biodiversity changes (Lemelin et al., 2010). Tourist market surveys about Canada's Rocky Mountain Parks and Churchill, Manitoba, the self-declared polar bear capital of the world, reveal last-chance motivations among a segment of travellers, suggesting short- to medium-term opportunities for increased visitation, as well as visitor education and interpretive activities (Weber et al., 2019; Lemieux et al., 2017; Groulx et al., 2017; Groulx et al., 2016; Dawson et al., 2010). There remain important uncertainties associated with longer-term tourist responses to degraded tourism assets. For example, while tourists have indicated their motivation and intent to visit the Rocky

Mountain Parks or Churchill, the number of tourists would decline if glaciers and polar bear populations were significantly impacted, and it is uncertain whether future generations of tourists with no experience or expectations of current ecotourism attractions would respond in the same way (Scott et al., 2007).

7.8.5 Moving forward

Tourism is Canada's largest service sector and is projected to become more competitive in the global market as a result of climate change (Scott et al., 2019; Roson and Sartori, 2016; OECD, 2015). The current literature is insufficient to determine the net economic impact of low- and high-emissions scenarios on sub-national tourism markets. Most adaptation in the sector is focused on addressing ongoing operational risks and emerging market opportunities. A key barrier to longer-term strategic adaptation planning remains the lack of integrated sectoral assessments that consider the full range of potentially compounding impacts at national and destination scales, and their interactions with other major drivers of tourism. Tourism is not part of any major national climate policy documents in Canada, nor is there a climate change response in national and most sub-national tourism strategies (Becken et al., 2020). Adaptation that is occurring is often at the company scale, with limited examples of coordinated adaptation planning at destination scale (e.g., Resort Municipality of Whistler, 2016).

7.9 Increased private sector involvement will accelerate adaptation across sectors

Despite growing awareness of climate change impacts, there is no widespread evidence of corporate adaptation in Canada. When adaptation does occur, it tends to focus on short-term actions to address physical risks, such as disruptions in construction and interruptions in supply chains. Increased involvement of the private sector would accelerate adaptation in Canada as a whole.

There is considerable uncertainty about the role of the private sector in climate change adaptation in Canada. While there are several case studies of Canadian businesses adapting to changing climate, particularly in the insurance and natural resources sectors, there is no evidence that such actions are broadly representative of the business community response to climate change. Actions that have been taken are frequently "low-hanging fruit" focused on site-specific vulnerabilities to the current climate that would have been implemented regardless of increasing risk in the future. Drivers for corporate adaptation include strategic incentives associated with physical risk, growing awareness among stakeholders of the need to adapt, and government regulation. The lack of available data on corporate adaptation may be influenced by the proprietary protection of internal information; however, there are also clear barriers to adaptation related to capacity and the short-term time horizons of most business operations. Additional effort, including research, could help reduce these barriers by identifying the appropriate roles for the private sector in supporting adaptation.

7.9.1 Introduction

The private sector, which is a key component of all the sectors discussed previously in this chapter, is both a source of risk and opportunity in Canada's approach to climate change adaptation. Research highlights the exposure of firms and industries to climate change, particularly how changing environmental conditions (e.g., more frequent extreme weather) could limit growth, disrupt operations and devalue investments. At the same time, firms and industries are critical actors in supporting the development of expertise, tools and knowledge related to adaptation.

Private sector engagement on climate change has historically focused on GHG emissions reduction rather than adaptation. However, governments, scholars and other organizations have started to explore the potential role of corporate adaptation, given the scale of the investment and resources required to manage climate change risks (Dougherty-Choux et al., 2015). The private sector could help to address demands for new technologies, expertise in risk management and modelling, capacity to scale up solutions beyond individual communities, and financial resources needed to achieve domestic and international adaptation objectives (UNFCCC, 2012; UNEP, 2012).

An overview of climate impacts and adaptation actions in Canadian businesses was included in multiple chapters of Warren and Lemmen (2014), with Kovacs and Thistlethwaite (2014) noting that corporate adaptation had been largely reactive, responding to variations in weather or extreme events, rather than involving analysis of long-term projected changes in climate. They further noted that successful adaptation can create new opportunities through expanded markets and products. They emphasized the scarcity of published research detailing climate impacts and adaptation on Canadian businesses, noting that in some cases adaptation actions may be under-reported for strategic reasons.

This section builds on the findings of Kovacs and Thistlethwaite (2014) by focusing on the status of corporate adaptation in Canada broadly. It complements the discussion of specific adaptation actions in other sections of this chapter, as well as a number of emerging issues of importance to the private sector, which are discussed in the Climate Disclosure, Litigation and Finance chapter of this report.

7.9.2 Corporate adaptation in Canada

Corporate climate change adaptation is defined as a "process of adjustment by companies to actual or expected climate and its effects through changes in business strategies, operations, practices and/or investment decisions" (Averchenkova et al., 2016, p. 520). Cases of corporate adaptation in Canada, as well as internationally, tend to be limited and difficult to generalize beyond sector and site-specific actions. Comprehensive literature reviews on corporate adaptation (Linnenluecke and Smith, 2018; Averchenkova et al., 2016) did not identify any recent (post-2011) Canadian studies on corporate adaptation.

Research findings from other industrialized countries indicate that firms may have extensive experience in making management or operational adjustments in response to changing economic or competitive environments, but they have generally been unable to translate that experience into making adjustments to changing climate (Linnenluecke et al., 2013). As a result, firms often separate climate change adaptation from the main value-driving processes, and instead treat it as a social responsibility issue (Thistlethwaite and Wood, 2018; Furrer et al., 2009).

It is often difficult, and perhaps not particularly useful, to distinguish actions supporting climate change adaptation from actions arising from existing risk management processes, given that anticipating and identifying external instability that could interrupt services is effective business continuity planning (Agrawala et al., 2011). Experts have argued that adaptation can be incorporated into standard enterprise risk management strategies by expanding the scope of risk assessment, prioritization and response actions to include climate change (Berkhout, 2012).

7.9.3 Adaptation actions

Risk management represents the main strategy for firms to reduce their exposure to climate change. In analyzing private sector adaptation, it is possible to differentiate between firm-level management actions to limit operational exposure to climate change, and the production of adaptation tools and services that help manage climate vulnerability (Schaer and Kuruppu, 2018). In terms of managing operational exposure, adaptation actions can be categorized as either "soft" or "hard" measures. "Soft" adaptations constitute "low-regret" measures, as they require limited investment and will yield benefits, although not always direct financial returns. They include activities such as climate change risk and opportunity assessment, adjusting operational practices, education and awareness programs, stakeholder and political engagement, and initiating partnerships with external actors. In contrast, "hard" adaptation measures require a significant investment or change in practice and operations, such as building or renovating structural defenses, relocating infrastructure or offices, or divesting from climate-exposed property and sectors (Averchenkova et al., 2016). Adaptation services represent a response to demand for climate change risk and disaster risk management, and include climate risk and opportunity assessments, mapping and communication technologies, climate change-resilient agricultural products, and new insurance products (e.g., parametric insurance).

Adaptation is growing in the corporate sector in response to many drivers, including increasing awareness of climate change among firms and sectors, strategic incentives associated with addressing physical risks, (Williams and Schaefer, 2013) and government regulations (Revell et al., 2009). In Canada, attention has focused primarily on the understanding and disclosure of physical risks. These include disruptions in construction, interruptions in supply chains, volatile energy costs associated with climate-related changes in demand, and closures or relocation in situations where employees or customers are unable to access a firm as a result of extreme weather (*see* Climate Disclosure, Litigation and Finance chapter; Certified Professional Accountants Canada, 2016a; Linnenluecke et al., 2011). Despite this emphasis, most firms struggle to measure physical risk that involves a lot of uncertainty and can be perceived as a more long-term concern (*see* Climate Disclosure, Litigation and Finance chapter; Mazzacurati, 2018).

Overall, there is limited evidence of clear responses to these drivers in Canada. A 2018 survey focused on business responses to climate change found that a majority of businesses are not taking action and one quarter of respondents suggest that they plan to engage in adaptation (Earnscliffe Strategy Group, 2018). One example is the insurance industry implementing strategies to support climate change adaptation in response to significant increases in water-related property damage (*see* Case Story 7.10; McBean, 2012). Climate change, combined with ageing infrastructure and development in areas where climate risks are high, have increased the number and costs of claims for flood damage (Henstra and Thistlethwaite, 2017).

Case Story 7.10: Insurance and climate change adaptation in Canada

The 2013 flood in southern Alberta was the costliest flood in Canada's history. Unfortunately, damage from overland flow of water from the flood did not qualify for property insurance, leaving many victims without resources for a full recovery. This gap in coverage led insurers to question whether Canadians had sufficient coverage for a changing climate where flood risk is anticipated to increase (Certified Professional Accountants Canada, 2016b). In response, insurers expanded their coverage to include overland flood damage, which had previously been unavailable in Canada. The availability of flood insurance provides an important tool for enhancing climate resilience by assigning premiums that create an incentive for property owners, businesses and communities to reduce their own exposure through expansion of coverage, and also by sharing the recovery costs from flood impacts when they occur (Thistlethwaite, 2016; IPCC, 2012). This engagement has enabled broader utilization of insurance expertise on risk modelling and strategies for risk reduction in efforts to promote adaptation (Surminski and Hankinson, 2018). This is particularly important in Canada where flood risk awareness and an understanding of insurance coverage are limited throughout the country (Thistlethwaite et al., 2017).

7.9.4 Knowledge gaps

Apart from a few examples in the insurance industry and natural resource sectors, there is a paucity of available research and data on corporate adaptation in Canada. Knowledge gaps start with the fact that corporate adaptation remains poorly defined in practice, which limits our understanding of which management, strategic or investment behaviours constitute adaptations. As a consequence, firms might be under-reporting adaptation since they are unsure if an action can be defined as such.

There also remains uncertainty over the motivation for and barriers to corporate adaptation. In Canada, most attention has focused on physical risks to business operations, but there is almost no research on the topics of firm awareness or regulation. There is also little research on the outcomes of corporate adaptation and its impacts on firms or the communities where they are located. Monitoring and evaluation of corporate adaptation could improve understanding of these outcomes (Surminski and Hankinson, 2018; Averchenkova et al., 2016). Finally, additional research would help to clarify the role of businesses in broader adaptation policies. The division of responsibility for adaptation between different stakeholders remains a source of ambiguity.

These knowledge gaps are particularly concerning for small and medium-sized enterprises (SMEs), which are more vulnerable to climate risk (Linnenluecke and Smith, 2018). SMEs lack the resources of their larger counterparts and may have greater difficulty prioritizing perceived long-term issues like climate change, given short-term concerns around sustaining operations. The 2018 survey of Canadian business responses to climate change found that SMEs were far less likely to be engaging in actions supporting adaptation (Earnscliffe Strategy Group, 2018). This gap is especially concerning since the recovery of a local community in the aftermath of a disaster is often contingent on the resiliency of local SMEs. There is evidence that 40% of SMEs fail to reopen after a disaster and that many are unable to sustain their business even if they do reopen (McKay, 2018). Without these SMEs, the local community may never support the economic growth and quality of life enjoyed before the disaster, since many provide critical services such as access to food and medicine.

7.9.5 Moving forward

While the lack of available data precludes strong conclusions about the status of corporate adaptation in Canada, it suggests that firms may lack sufficient adaptive capacity. Most firms face limitations in the human and financial resources required to interpret climate change data, assess the costs and benefits of actions, and incorporate the flexibility required to adjust strategies as new information emerges (Wedawatta and Ingirige, 2016; Downing, 2012). Research also suggests that firms are organizationally biased in favour of short-term and local scales, and resistant to acting when faced with temporal and spatial uncertainty associated with climate change (Bansal et al., 2017; Slawinski et al., 2017). The lack of adaptive capacity and absence of organizational interest in addressing climate change call into question the current ability of businesses to have a role in supporting climate change adaptation.

7.10 Moving forward

7.10.1 Knowledge gaps and emerging issues

It has been noted for more than a decade that, in most situations, existing knowledge is sufficient to start taking adaptation action in Canada (Lemmen et al., 2008). Nonetheless, the need to accelerate the implementation of adaptation measures has been acknowledged in both scientific and policy analyses at the global and national scale (e.g., Canadian Council of the Academies, 2019; IPCC, 2018; Government of Canada, 2016; UNFCCC, 2015). Risk and opportunity assessments are frequently a prerequisite to enhancing investment in adaptation. A wide range of methodologies are available, with the most appropriate being determined by many factors, including the scope and goal of the assessment and available resources (e.g., British Columbia Ministry of Environment and Climate Change Strategy, 2019). The Canadian Council of Academies undertook an assessment to prioritize climate change risks for Canada and the Canadian federal government, based largely upon collective expert judgement (Canadian Council of Academies, 2019). Major climate change risk areas included some of the sectors discussed in this chapter as stand-alone sections (agriculture, fisheries, forestry) as well as themes woven throughout (e.g., physical infrastructure and governance and capacity). Importantly, analysis considered the potential to reduce damages through adaptation, in addition to the likelihood and potential consequences associated with each risk. Of the topics addressed in this chapter, infrastructure (including transportation) and agriculture were identified as having the highest adaptation potential, and fisheries the lowest (Canadian Council of Academies, 2019).

While many factors contribute to the lack of progress on adaptation, uncertainties and gaps in knowledge are frequently highlighted as a barrier to action (Eyzaguirre and Warren, 2014). Knowledge gaps specific to individual sectors are identified in the preceding sections of this chapter and the publications cited in those sections. There are also a number of emerging cross-cutting issues that represent important knowledge gaps with respect to economic sectors in Canada.

The state of adaptation in the private sector

While climate disclosure is emerging as a key instrument for understanding how the private sector is assessing and responding to physical climate risk (*see* Climate Disclosure, Litigation and Finance chapter; TCFD, 2017), such information is largely restricted to large, publicly-traded companies. Very little information is available on adaptation actions undertaken by small and medium-sized businesses, even though many are highly exposed to climate risks. Benchmark surveys (e.g., Earnscliffe Strategy Group, 2018) provide a foundation for future work.

Transnational climate impacts

Also referred to as transboundary or indirect impacts, these refer to climate impacts that occur in one country and affect the adaptation measures taken within other countries (Hedlund et al., 2018). These could relate to impacts on global supply chains, international competitiveness, financial flows and trade (*see* International Dimensions chapter). For example, flooding in Thailand in 2011 affected global electronics and automotive supply chains, with economic implications for many countries and corporations (Shughrue and Seto, 2018). The magnitude of such vulnerabilities in Canada is essentially unknown, although research elsewhere indicates that open and export-intensive economies are particularly exposed (Hedlund et al., 2018).

Interdependencies

Much of the existing sectoral research examining climate impacts in Canada, and elsewhere, has been focused on individual sectors. While the importance of understanding interdependencies between sectors is growing (*see* Section 7.7.3), quantitative analysis of these connections remains limited. Without such analysis, there is potential to significantly underestimate the risks associated with climate change (Canadian Council of Academies, 2019).

Potential for stranded assets

Understanding of the risk of assets losing significant value as a result of policy changes to address climate change is well developed, particularly with respect to the energy sector (e.g., IPCC, 2018; IRENA, 2018). Far less attention, particularly in Canada, has been given to stranded assets that could result from the physical impacts of climate change (*see* Circle of Blue, 2018 for examples related to water resources). In Canada, closure of the rail link to the Port of Churchill for 18 months as a result of flooding represents temporary stranding of the port assets (*see* Section 7.7.3).

Strengthened economic analysis

A commonly cited barrier to adaptation action is the absence of a strong business case (Eyzaguirre and Warren, 2014). While examples of detailed economic analysis, including cost-benefit, cost-effectiveness and multi-criteria analyses, exist (e.g., UNFCCC, 2011) there is limited application of these techniques in Canada (*see* Costs and Benefits of Climate Change Impacts and Adaptation chapter). At a national scale, quantitative analysis of economic impacts under a range of future climate scenarios is lacking, potentially hindering action to enhance climate resilience and reduce greenhouse gas emissions.

7.11 Conclusion

Examination of the sector-specific key messages and associated discussions in this chapter reveals several integrative conclusions:

1. A tremendous breadth of sector activities are impacted by climate change, which is evident despite authors focusing on a limited number of key issues per sector. While research has traditionally focused on direct climate impacts on production (e.g., agriculture, forestry, fisheries and hydroelectricity) and to a lesser degree on consumer demand (e.g., energy and tourism), it is clear that cumulative and cascading impacts of climate change ultimately affect virtually all elements of sectoral systems. This breadth emphasizes the value of comprehensive assessments of both risks and opportunities to inform adaptation.
2. It is important to understand the interconnections within and between multiple sectors (*see* Section 7.7.3). For some sectors, such as transportation, this is particularly evident given its critical role in supply chains (*see* Section 7.7.3). The reliability and resilience of Canada's freight transportation system regarding access to domestic and international markets is a critical issue for the sustainability of agriculture in Canada (*see* Section 7.4.3). The response of the forest sector to wildfire has implications for many other sectors, including costs related to evacuations, damage to buildings, roads, pipelines and other physical infrastructure, shutdown of businesses and industries, and insurance costs (*see* Section 7.2.2). Emerging tourism in the Arctic is having unforeseen social and cultural impacts, and is placing stress on search and rescue capacities (*see* Section 7.8.3). Further modelling studies could help elucidate the nature of these interconnections (*see* Section 7.7.4).
3. Adaptation is occurring within all sectors, but needs to be accelerated. This applies to actions that reduce risks and those that take advantage of new opportunities. It is noteworthy that successful adaptation not only reduces the vulnerability of sectors and communities within Canada, but also enhances global resilience (e.g., food security) (*see* Sections 7.3.1, 7.4.3). Most examples of implemented adaptation action relate to those sectors where the direct impacts of climate

change are already evident. Evidence of widespread adaptation within the private sector is particularly limited, despite the key role that it plays in all the sectors discussed here (*see* Section 7.9.2). The need for collaboration using a systems approach that includes producers, asset managers, regulators, researchers and relevant stakeholders is a commonly identified need (*see* Sections 7.2.3, 7.4.1, 7.5.5, 7.6.4, 7.7.4). Finally, it is extremely important to monitor and report on adaptation measures that have been implemented in order to inform future plans (*see* Sections 7.5.4, 7.6.4, 7.10).

4. There is urgency associated with accelerating adaptation action. Urgency is most clear where current climate risks are not adequately managed and where investment decisions made today have implications extending for many decades to come: for example, decisions regarding infrastructure (*see* Sections 7.6, 7.7, 7.8), forest management (*see* Section 7.2) and mining reclamation (*see* Section 7.5). While proactive adaptation is generally recognized as being more effective and cost-efficient than reactive approaches (i.e., responding to impacts as they happen), and provides opportunities for innovation and competitive advantage (e.g., Eyzaguirre and Warren, 2014), it is recognized that investment decisions in both the public and private sectors take place within a context of competing priorities and associated opportunity costs. Comprehensive assessments of risks and opportunities can be critical in identifying action priorities, particularly those that include consideration of adaptation potential (*see* Sections 7.7.3, 7.8.5, 7.10). There is also an urgent need to reduce greenhouse gas emissions as the range of viable adaptation options decreases under higher rates of climate change, and limits to adaptation can be exceeded (IPCC, 2018, 2014).

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