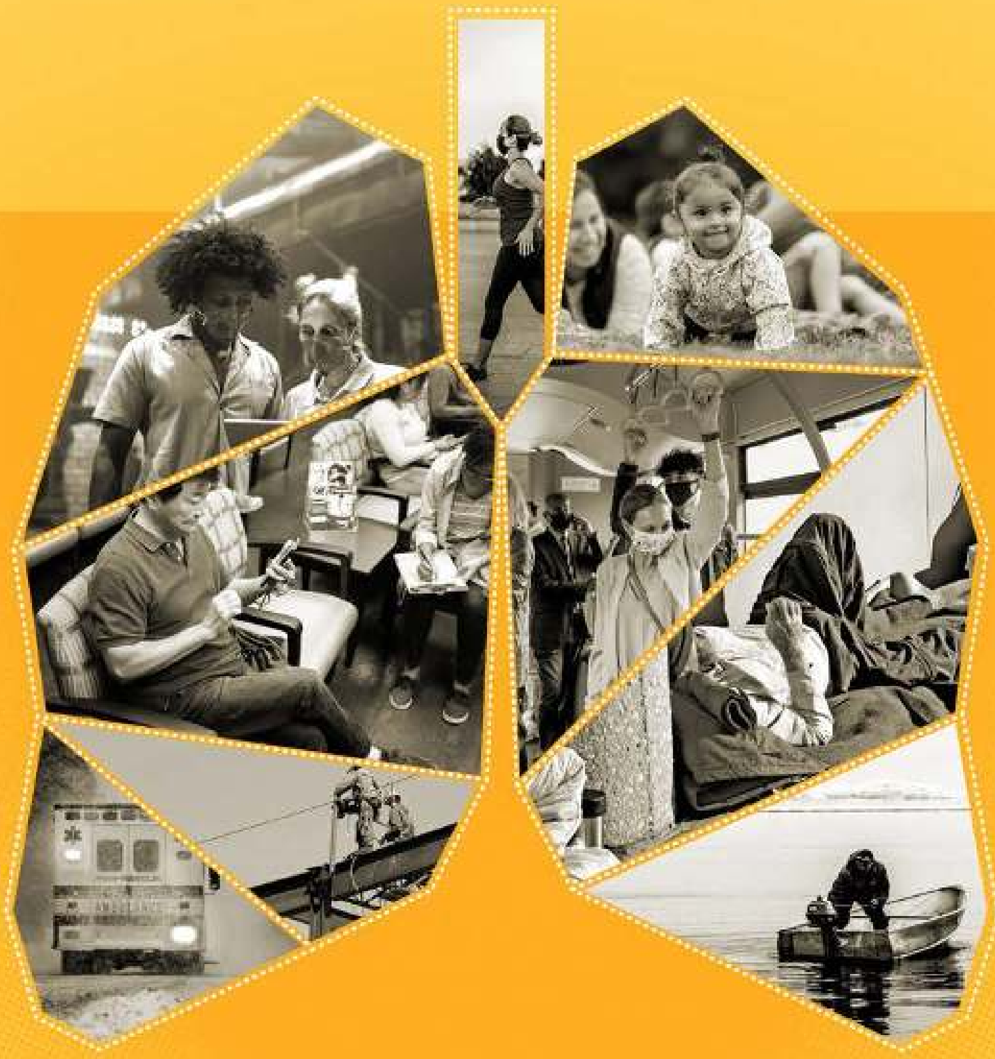
THE HEALTH COSTS OF CLIMATE CHANGE

HOW CANADA CAN ADAPT, PREPARE, AND SAVE LIVES



CANADIAN INSTITUTE FOR CLIMATE CHOICES
INSTITUT CANADIEN POUR DES CHOIX CLIMATIQUES

JUNE 2021

CONTENTS

The **Canadian Institute for Climate Choices** is an unparalleled collaboration of experts from a diverse range of disciplines and organizations across the country.

As an independent, non-partisan and publicly funded organization, we undertake rigorous research, conduct in-depth analysis, and engage a diverse range of stakeholders and rightsholders to bring clarity to the climate challenges and transformative policy choices ahead for Canada. Learn more at climatechoices.ca.

FOREWORD

The health effects of climate change are a reality to many people living in Canada. The climate is changing, and the effects that this is having on human health will intensify over the coming decades. Some of these effects will be dramatic enough to become news stories: wildfires and floods will destroy homes and workplaces. Fierce storms will leave people in the dark for days. But others will be harder to illustrate, such as the thousands of deaths per year from fine particulate air pollution or the changing patterns of infectious disease outbreaks.

This report begins to identify and quantify some of the health-related costs of climate change. It also acknowledges that many costs cannot (yet) be quantified—it only describes the "known knowns." There are many "known unknowns" related to climate change on which we are not yet able to put a dollar value. These unknown costs could be even greater than the known ones.

To protect everyone in Canada, a whole-of-government approach is needed. Responses cannot be relegated to one level or segment of government or society. The problem is complex, and the solutions will have to be, too. The climate crisis is not just an environmental issue: it's a public health issue. It's also a housing issue. It's an education issue. It's an economic issue. It touches every aspect of our lives.

The health effects of climate change will affect us all in some way. It's clear from the data in this report that acting to mitigate emissions quickly will save lives and curb costs over the next decades. We will also need to adapt, changing our cities and communities and our systems too so that people are better equipped to survive a quickly shifting climate.

Climate change is an escalating public health emergency, and we need to start treating it that way.

Ian Culbert
Executive Director
CANADIAN PUBLIC HEALTH ASSOCIATION

Our ongoing research into the costs of climate change includes the following reports:

2020

TIP OF THE ICEBERG
FALL 2020

If we think of the costs of climate change as an iceberg ahead, this introductory paper zooms in on the tip of the iceberg—the known and measurable hazards—as well as the contours of what lies below the water.

HEALTH
SPRING 2021

A closer look at health costs and adaptation opportunities, built around our analysis of the costs of heat-linked health burdens, Lyme disease, and air quality changes. The report includes a discussion of mental health impacts and other difficult-to-quantify health costs.

INFRASTRUCTURE
FALL 2021 - WINTER 2022

A focused analysis on infrastructure costs and adaptation opportunities, built around our modelling of climate-induced impacts to flooding, transportation infrastructure, and electricity systems. We also take a deeper dive into how climate change is affecting Northern infrastructure, including exploring the impacts on individuals and communities that economic studies often underemphasize or leave out.

MACROECONOMIC
SPRING 2022

Using national macroeconomic modelling of potential climate change impacts to vulnerable sectors and assets, this report will outline the implications of a changing climate on economic productivity and well-being.

2022

EXECUTIVE SUMMARY

INTRODUCTION

Climate change is not just an environmental and economic threat, it is also a threat to public health. Climate change will make existing health inequities worse and increase costs to Canada's health system and economy—unless governments work together to invest in preparation and prevention.

The impacts of climate change are already causing illness, death, and economic damage in Canada. Wildfires and floods destroy homes and disrupt lives and livelihoods. Heat waves can be deadly, especially to the elderly, and to people working outdoors. These are the most dramatic and visible examples. But the changing climate is also altering the places and landscapes that people call home—sometimes slowly and sometimes rapidly, introducing new risks, such as new diseases or different ice or snow conditions.

Humans are adaptable. But climate change is shifting the nature of these threats at an unprecedented pace.

As with the COVID-19 pandemic, no one in Canada will be immune to the health effects of climate change. And as with the pandemic, the impacts of climate change will be worse for those who are already at risk of poor health and face barriers to affordable housing, food security, and healthcare.

Our report shows that climate change will make existing health inequities worse and concludes that addressing climate change requires recognizing the systemic issues that place some people at greater risk. Failing to do so will lead to higher costs, more illness, and additional deaths from climate change impacts.

The risks to people across Canada are twofold. First, the impacts of climate change on health are increasing rapidly. Second, health and social systems—which are necessary to weather illnesses and loss—are often unable to meet the needs of those most vulnerable to climate-related health hazards. Yet despite these growing risks, preparation for the health impacts of climate change remains inadequate.

In this report, we outline future threats by projecting climate impacts to health in the coming decades and discuss opportunities to protect the health of people in Canada.

Our research finds that protecting the health of people in Canada in the face of climate change is not just about preparing for specific risks like heat waves or Lyme disease. It is also about addressing factors like poverty and racism that make people more vulnerable and ensuring access to housing, healthcare, employment, and education. Health and climate change policy objectives can't be viewed in isolation—they are fundamentally interconnected with the broader social and economic policy landscape. Addressing the root causes of climate-related health impacts as well as their symptoms, therefore, requires coordination and collaboration across and within governments.

METHODS

This report combines new analysis and evidence from the existing literature to highlight key health risks and costs across Canada from a changing climate.

Projections of health costs

We estimated how climate-related health costs could change between now and the year 2100 for three key health impacts:

A. The impact of declining air quality associated with increasing ground-level ozone concentrations

B. Increasing incidence of Lyme disease

C. The health effects of hotter temperatures

For each of these climate-related health risks, we analyzed the impacts under both low and high global greenhouse gas emissions scenarios.

To illustrate the benefits of proactive health adaptation, we also examined the potential cost savings from two potential adaptations to heat waves.

Losses and damages that cannot be quantified

Air quality, Lyme disease, and heat are only a few of the many possible threats that climate change poses to health. Many other impacts require attention even if it is not currently possible or appropriate to quantify them.

To paint a broader picture of the effects of climate change on health in Canada, we summarize current understanding of climate-related mental health effects, impacts on Indigenous People's cultures and food security, and risks to Canada's healthcare facilities.

FINDINGS

▶ Ground-level ozone and other impacts to air quality are a clear threat to health.

As temperatures rise, concentrations of ground-level ozone (a major component of smog) will increase across Canada. Our modelling shows that, with the temperatures projected for the end of the century, average summer ozone concentrations could increase by 22 per cent.

As ground-level ozone increases, so do deaths and healthcare costs. Unless action is taken, future healthcare costs of ozone exposure could increase to one quarter of current healthcare costs linked to cancer. The costs of death and lost quality of life are even greater—we estimate these costs will be $87 billion per year by mid-century and $246 billion per year by the end of the century.

Over a ten-year period at the end of the century, ozone-linked respiratory illnesses could be associated with 270,000 hospitalizations and premature deaths—more than the population of Gatineau, Quebec.

▶ Lyme disease impacts are uncertain, but they are likely smaller than many other climate change impacts on health.

Warming temperatures from climate change are creating ideal conditions for the spread of the ticks that carry Lyme disease into many parts of Canada where they have never been seen. We project that, under a low-emissions future, additional cases of Lyme disease due to demographic change and climate change will rise to about 8,500 annually by mid-century and 9,900 by the end of the century, up from an average of about 600 cases per year.

Our analysis projects Lyme disease to be the least costly of the health impacts we modelled. Our modelling estimates that healthcare costs of Lyme disease will be on the order of $3 million annually by mid-century.

Lyme disease is challenging to model and future risk is uncertain, but our results provide an important starting point for discussion of potential future impacts and costs.

▶ Heat waves will continue to become more frequent and severe.

The number of days with heat-related deaths is increasing.

Between 1971 and 2000, Ontario and Manitoba had an average of about 50 days per year with temperatures above thresholds where heat-related deaths begin to occur. In the 2050s—when children born today are about 30 years old—the number of days above that threshold will increase by 1.5 times in Ontario and Manitoba.

Our analysis suggests that even under the low-emissions scenario, heat-related hospitalization rates will increase by 21 per cent by mid-century compared to the current average and double by the end of the century. Further, the costs of death and reduced quality of life from heat-related deaths are substantial. By mid-century, we project these costs will range from $3.0 billion to $3.9 billion per year.

Rising temperatures are projected to have a large negative impact on productivity, especially in economic sectors where work takes place outdoors or in poorly cooled spaces. Our modelling estimates that under a high-emissions scenario climate change could lead to a projected loss of 128 million work hours annually by end of century—the equivalent of 62,000 full-time equivalent workers, at a cost of almost $15 billion.

▶ Impacts to mental health could be among the costliest climate-related health impacts for Canada.

In the years ahead, climate change will increase the frequency of weather-related disasters and accelerate permanent changes to landscapes and ecosystems. The psychological impacts of these changes will increase the risk of mental illness for many people across Canada, affecting mental health, eroding well-being, and imposing substantial costs on individuals and governments.

Mental illness in Canada is already a critical issue with major social and economic implications. Productivity losses associated with depression currently cost about $34 billion per year in Canada; anxiety is estimated to cost $17 billion per year. An increase in rates of mental illness caused by climate change could therefore have major costs.

▶ It is not possible or appropriate to assign every loss a dollar value—but that does not mean they are not important.

Many people and communities are highly exposed to climate change impacts that threaten health, safety, culture, and ways of life. For example, in the North thawing permafrost and changing ice and snow conditions make homes uninhabitable, threaten drinking water supplies, make hunting and harvesting activities more challenging, and cut off community access to emergency medical care and services. Loss of traditional food sources also has a profound impact on the cultural and spiritual well-being of Indigenous Peoples, in addition to increasing food insecurity, which they already experience at a rate of three to five times the national average. These losses may not be on balance sheets or in government budgets, but to overlook them risks ignoring some of the most critical impacts of climate change on health and well-being.

▶ In addition to a growing burden of climate-related impacts, health systems in Canada are also faced with physical risks to health infrastructure.

The growing risk of weather-related disasters from climate change is not only a threat to the health of people in Canada, but a threat to the country's hospitals, clinics, and emergency response facilities. Despite the importance of these facilities, less than 20 per cent of health authorities have assessed the vulnerability of their facilities to climate change risks, and about eight per cent of health centres in Canada are located in flood risk zones.

SOCIAL DETERMINANTS OF HEALTH

In this country, health is defined more by a person's postal code than their genetic code.

While the COVID-19 pandemic has affected everyone in Canada, it has hit the most vulnerable hardest. And like COVID-19, the impacts of climate change will not be experienced equally.

From asthma complications to high blood pressure, the likelihood that a person experiences poor health throughout life is largely determined by their social context. Income, access to quality housing, food and water security, and education shape the health of each and every person across Canada. These factors are influenced by where they live, their race, and their gender.

Indicators of health inequity have been trending in the wrong direction in Canada. For example, between 1991 and 2016, the difference in premature death risk between a poor woman and wealthy woman widened by about 40 per cent (Shahidi et al., 2020). Similarly, between 1996 and 2011, the gap in life expectancy between men who did not graduate from secondary school and men with university degrees increased by over 20 per cent (Marshall-Catlin et al., 2019).

Climate change is likely to increase these gaps in the coming decades.

Racism, poverty, and geographic remoteness have already put many people in Canada at a disadvantage by increasing their exposure to health hazards and causing poor baseline health. Without adaptation, the climate change impacts on Canada's horizon will worsen the health divide.

Those who are not personally at high risk can still be affected. Most people across Canada have family members and friends who will be more vulnerable to climate change health impacts. Healthcare costs may increase, potentially affecting quality of service and costing both taxpayers and patients. And as with the COVID-19 pandemic, impacts to labour productivity will affect the broader economy.

Adapting to climate change means addressing both the symptoms of climate change health impacts and the root causes of health inequity and vulnerability. Addressing symptoms includes measures like improving emergency response systems for high heat and poor air quality events, retrofitting homes and buildings to improve cooling and ventilation, and developing vaccines for new climate-driven diseases. Addressing the root causes will require investing proactively in measures that improve health and well-being for all, such as increasing access to health services and ensuring everyone has healthy air, water, and food.

HEALTH ADAPTATION POLICY NEEDS TO CATCH UP

As the world discovered in 2020, countries that were prepared and proactive when faced with COVID-19 fared far better than those that were not.

The COVID-19 pandemic tested the capacity of Canada's health systems. The economic costs were profound, and the human impact will be felt for years to come. We have seen how difficult it is for governments to catch up to a risk when it outpaced existing safeguards.

There are, of course, many differences between climate change and the sudden emergence of a novel pathogen. In particular, we are well aware of the threats from climate change and can reasonably predict what will happen next. Yet, as with COVID-19, if Canada does not prepare for the impacts of climate change, the crises ahead may overwhelm public health and healthcare systems.

The challenge ahead is profound. Our analysis shows that the impacts of climate change could cost Canada's healthcare system billions of dollars and reduce economic activity by tens of billions of dollars by later this century. Adding the value of lost quality of life and premature death, the societal costs of climate change impacts on health could amount to hundreds of billions of dollars.

Over the past decade, adaptation policies and actions have not kept pace with the scale of emerging climate change risks to health and well-being. Only $71 million has been earmarked specifically for health adaptation programs in federal budgets since 2017—about three per cent of all climate change adaptation funding, or about 0.3 per cent of total federal climate change program funding.

Canada is behind when it comes to adaptation policy, and now is the time to catch up. Policy makers will have to expand their arsenal to prepare for the risks ahead. Because of the broad scope of policies that affect health outcomes, intra- and inter-governmental collaboration and coordination is essential. National adaptation funding and coordination should reflect the importance of climate change health impacts and the imperative of treating the symptoms of climate-related diseases and vulnerability, while also addressing the root causes.

RECOMMENDATIONS

As Canada moves beyond the COVID-19 crisis, governments have an opportunity to safeguard against future health threats. This is a critical juncture to redefine how public policy advances health and climate change adaptation.

The following recommendations provide a starting point based on our analysis of climate-related health risks on Canada's horizon:

1 All orders of government should implement health adaptation policies to address both the symptoms and root causes of climate-related health threats.

Policies that tackle the symptoms of health impacts can play a clear role in reducing risks. For example, governments can enhance warnings about heat and poor air quality and ensure emergency response systems are primed for more extreme weather. Despite their benefits, however, health adaptation efforts that are limited to symptoms and proximate effects will ultimately be unable to keep up with growing and unpredictable climate change impacts. That means that governments should also implement policies that address the root causes of vulnerability and exposure to climate health hazards.

2 Canada's emerging national adaptation strategy should map all key adaptation policy levers across government departments and orders of government against top climate health impact areas.

When developing the forthcoming national adaptation strategy, the Government of Canada should explicitly recognize the decentralized nature of health adaptation and resilience building. It should work with provincial, territorial, Indigenous, and local government partners to identify bodies that make policy decisions to improve health resilience. Mapping these accountabilities can help start the discussion about how to coordinate policy decisions that advance health adaptation across orders of government.

3 Central agencies in federal, provincial, and territorial governments should explicitly incorporate health resilience into climate lenses to inform cost-benefit analyses and policy decisions.

All government departments should be directed to identify their role in climate change health adaptation and resilience and to take responsibility for those roles in departmental goals, projects and decisions. Departments should consider not just overall quantitative costs and benefits of alternative actions with respect to climate change health impacts but also the distribution of costs and benefits—recognizing that improving the circumstances of disadvantaged groups builds overall resilience.

4 Governments should invest in research on emerging, unknown, and local climate change health impacts.

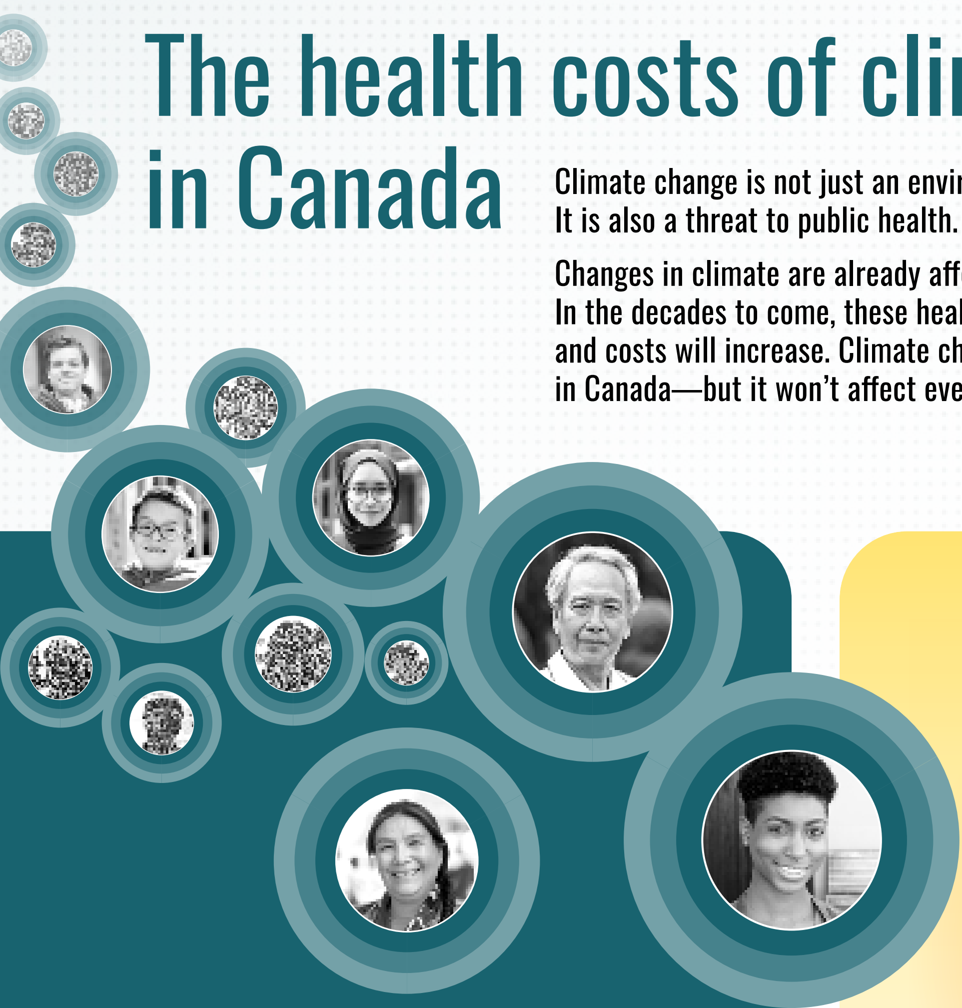
Successful health adaptation policy must address health risks broadly, not only the narrower set of impacts of climate change that are most studied. Broad risks include mental health impacts, the effects of changes in wildfire regimes on air quality and respiratory health, the vulnerability of health systems themselves to climate change and extreme weather, and the direct and indirect effects of ecosystem change on health and well-being. Provincial, territorial, Indigenous, and local governments should also invest in better understanding the regional and local health implications of climate change, including the exposure and sensitivity of disadvantaged groups.

This report is the second in the Costs of Climate Change series. Our first report, *Tip of the Iceberg*, provides an introduction to the known and unknown costs of climate change for Canada. Forthcoming reports will analyze the cost of climate change to Canada's infrastructure and the national economy.

The health costs of climate change in Canada

Climate change is not just an environmental and economic threat. It is also a threat to public health.

Changes in climate are already affecting the health of people in Canada. In the decades to come, these health impacts will intensify, and costs will increase. Climate change will affect everyone living in Canada—but it won't affect everyone equally.

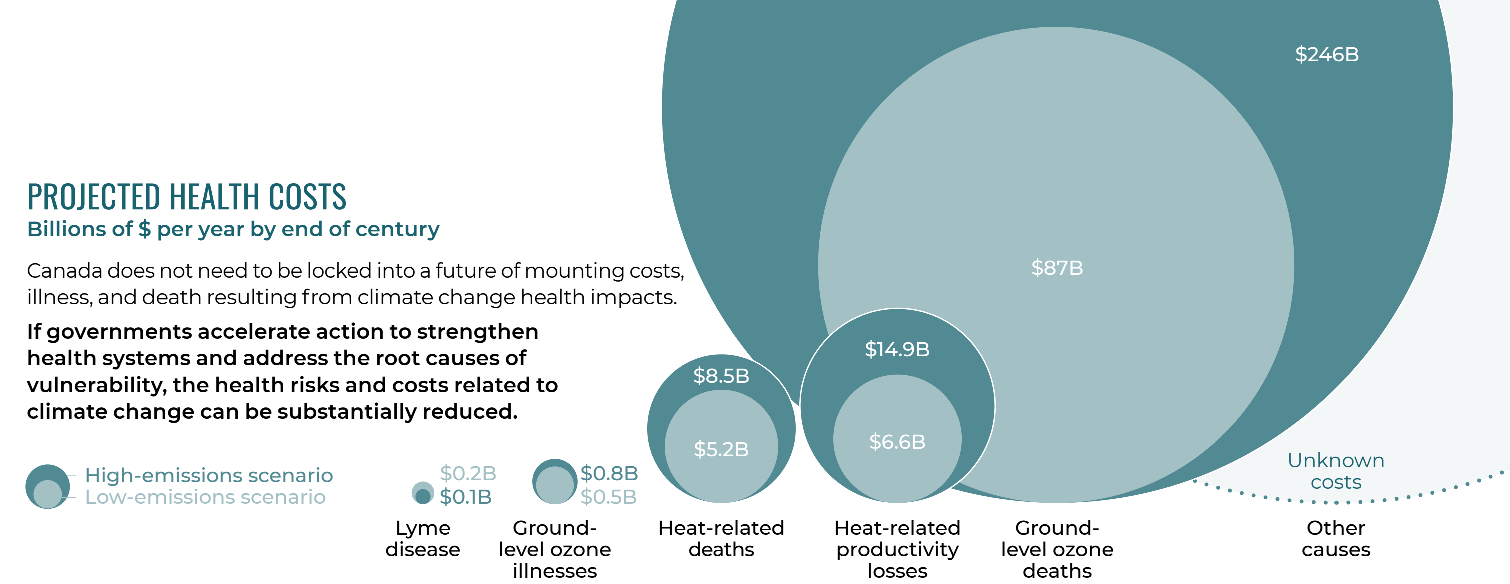


PROJECTED HEALTH COSTS

Billions of $ per year by end of century

Canada does not need to be locked into a future of mounting costs, illness, and death resulting from climate change health impacts.

If governments accelerate action to strengthen health systems and address the root causes of vulnerability, the health risks and costs related to climate change can be substantially reduced.



Three factors influence people's vulnerability to climate-related health impacts:

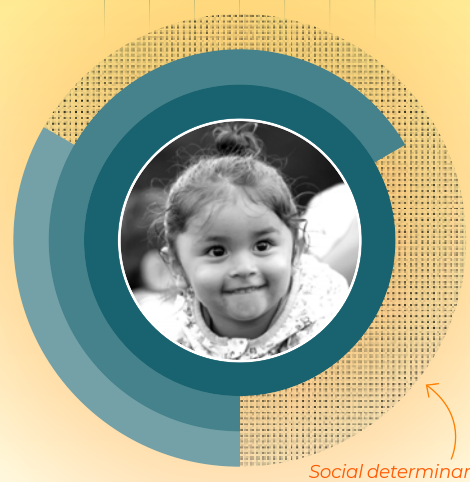
Exposure: How much a person comes in contact with climate-related hazards—for example, exposure to heat is reduced if a person has access to a home with air conditioning.

Sensitivity: Factors such as age, pre-existing health conditions, and social and economic conditions—for example, unmanaged diabetes—can increase sensitivity to heat waves and infectious diseases.

Capacity to adapt: The ability to avoid, prepare for, and cope with exposure and sensitivity—for example, someone who earns a high income likely has more access to prescription medications and health services than those who earn less.

Social Determinants

Income · Education · Race · Age · Literacy · Working conditions



Social determinants reduce protection

Some people are more vulnerable because of age or genetics. Others are put at greater risk by economic disadvantage and discrimination.

Health is determined more by a person's postal code than their genetic code. From asthma complications to high blood pressure, the likelihood that a person experiences poor health—which also increases their vulnerability to climate change—is largely determined by their social context.

Unless governments work together to invest in preparation and prevention, climate change will worsen these existing health inequities and increase costs to Canada's health system and economy.

Climate Impact

Ecosystem changes · Heat waves · Wildfire smoke · Permafrost thaw · Air pollution · Severe weather · Floods

Climate impacts reduce protection

Many people in Canada have already experienced health effects related to climate change.

Some effects and costs are easy to quantify, such as heat-related hospitalizations, but the full scope and scale of potential climate change health impacts in Canada are uncertain. While some emerging threats, like mental health impacts, are difficult to estimate and model, they are nonetheless important and deeply felt across the country.

Social determinants will dictate the severity of health outcomes that people experience from climate change impacts.

Adaptation

Cooling centres · Primary healthcare · Medications · Disaster response · Food and water · Flood protection · Heat warning systems · Housing · Education and outreach

Adapting to climate change requires supporting the health of people in Canada over the coming decades.

It's essential to **treat the symptoms** of climate-related health impacts. This involves preventing or reducing the negative impacts of specific health hazards related to climate change as they occur—for example, by increasing emergency response capacity, and developing early warning systems.

Addressing root causes is equally important. This requires tackling the factors that make people vulnerable to climate health hazards—for example, by reducing food and water insecurity, increasing access to preventive healthcare, and reducing economic inequities.

1 INTRODUCTION

The COVID-19 pandemic exposed long-standing vulnerabilities in health and social systems across Canada. The pandemic has caused immeasurable pain and loss, stretched health systems, raised unemployment to its highest levels in 45 years, and caused an economic recession. All of these impacts have disproportionately affected disadvantaged groups—people struggling with the effects of poverty, racism, discrimination, precarious employment, and limited healthcare access (Guttmann et al., 2020; OMH, 2020). It is clearer than ever that good health is intimately tied to healthcare access, stable housing, financial resources, and water and food security, among other factors.

Over time, climate change could further expose vulnerabilities in our society. A changing climate is expected to intensify risks to health and well-being across Canada. Without preparation for these risks, the impacts to quality of life and to the Canadian economy will be substantial. Like COVID-19, these impacts will disproportionately affect disadvantaged people.

The impact of climate change on public health is becoming increasingly clear. Smoke from larger and more frequent wildfires is exacerbating asthma across parts of Western Canada (Kirchmeier-Young et al., 2019; Matz et al., 2020). The aftermath of climate-related fires and floods is eroding mental health (Belleville et al., 2019; Watts et al., 2020). Heat waves are becoming more frequent and deadly (Berry et al., 2014; Martin et al., 2012). Further, landscapes that have long sustained communities are rapidly changing in ways that are harming well-being and threatening ways of life (Cunsolo & Ellis, 2018; Ly & Latimer, 2015; McDowell, 2020; Middleton et al., 2020).

The health impacts of climate change experienced to date are just a prelude and could become much more widespread and severe across Canada in the decades ahead. Continued climate change will increase the frequency and severity of climate-related hazards. These hazards, including weather-related disasters and irreversible environmental changes, could intensify a broad range of physical and mental health impacts (ITK, 2019; PHAC, 2017; Schnitter & Berry, 2019; Watts et al., 2019).

Health impacts linked to climate change will disproportionately weigh on people who are already disadvantaged, unless additional steps are taken to prepare for coming hazards (Patterson & Veenstra, 2016; TRC, 2015; Watts et al., 2020; WHO, 2015). Any person can be more or less vulnerable to climate-related health impacts because of their age, their genetics, or pre-existing health conditions. But the playing field is not level. Groups that are disadvantaged because of disproportionate exposure to hazards, a lack of stable housing, challenges in accessing healthcare, and poverty are often more vulnerable to the health risks of climate change (Adger et al., 2014; Doiron et al., 2020; Ready & Collings, 2020; Waldron, 2018).

Without careful preparation, no household in Canada will be spared the human and economic costs of health impacts related to climate change. Health systems may be increasingly strained, limiting their capacity to offer quality care to everybody (Austin et al., 2015; Paterson et al., 2014). Impacts to labour productivity could affect economic growth and incomes at a national scale. Even those who are not personally at high risk will have family members and friends whose health could be compromised.

Canada does not need to be locked into a future of mounting costs, illness, and death resulting from climate change health impacts. If governments accelerate action to strengthen health systems and prepare for a climate that is increasingly threatening well-being in Canada, the health risks of climate change can be substantially reduced (Austin et al., 2015; Hess et al., 2014).

This report responds in two ways to the growing challenge of climate-related health risks in Canada and the need to adapt and build resilience without delay.

First, this report helps articulate the magnitude of the problem. Charting the risks that climate change poses to health and well-being offers a new perspective on climate change adaptation policy—viewing it not as an environmental or healthcare policy problem with technical solutions but as a systemic challenge that requires integrated responses across and between governments. Improving decision makers' understanding of why health risks exist is a prerequisite to efficiently directing attention and resources to solutions that improve health resilience.

Second, this report outlines a path forward for solutions that address root causes of risk. Until now, health adaptation to climate change in Canada has largely focused on what we call "reducing symptoms"—preventing or reducing the negative impacts of specific climate change health hazards. Yet this approach is incomplete: solutions are also needed to address the root causes of climate-related health hazards and what makes people vulnerable to them. Better coordination within and across all orders of government is needed to tackle the root causes directly.

This report combines new analysis with evidence from the literature in order to highlight key health risks and costs across Canada from a changing climate. It helps to address gaps in understanding of the health implications of climate change by evaluating costs of some important impacts. It also summarizes what is known about the social and economic dimensions of climate change health impacts, including their potential scale. We then illustrate opportunities to take health adaptation actions that treat climate change symptoms and address root causes.

The rest of this report is structured as follows. Section 2 lays out a map of the linkages between health, climate, and impacts on Canada's economy and society. Section 3 lays out our methodological approach. Section 4 explores new analysis that quantifies health costs in Canada for key areas (ground-level ozone, Lyme disease, and illnesses from heat). Section 5 takes a wide-angle view, exploring hard-to-quantify (but hugely important) health impacts. And Section 6 summarizes our main findings and offers recommendations.

2

CLIMATE CHANGE, HEALTH, AND ADAPTATION

The impacts of climate change on public health in Canada will depend on three things:

1. Changes to the climate that pose hazards to health
2. Social and economic factors that determine who is vulnerable
3. Choices about how to prepare and adapt

Climate change health hazards

Human health has always been intimately connected to the climate. For millennia, Indigenous Knowledge Holders have observed and shared insights into the relationship between health and the land. Knowledge of weather patterns, hazards, and the land are often woven throughout Indigenous cultures and knowledge systems (Cruikshank, 2007; ITK, 2019; Prairie Climate Centre, 2019).

While humans have adapted for millennia to the environmental hazards, risks, and opportunities of their times, anthropogenic climate change and other environmental disruptions are creating new threats at an unprecedented pace. Canada is moving into an era where climate could impact human health more frequently, more severely, and with less warning than ever before. Table 2.1 provides an overview of the health hazards that climate change is expected to exacerbate in Canada in the coming years and decades, based on what is understood so far.

Table 2.1

Threats to health

Category	Climate and related environmental hazards	Health impacts
TEMPERATURE EXTREMES	• More frequent and more severe heat waves are highly likely across most of Canada	• Increased heat-related illness • Exacerbated cardiovascular disease, diabetes, and respiratory diseases • Reduced cold exposure in some places
AIR QUALITY	• Warmer temperatures are likely to promote smog and degrade urban air quality • More frequent and larger wildfires across much of Canada will increase exposure to smoke • Temperature and precipitation shifts will affect where and how much pollen is in the air	• Increased shortness of breath • Worsening pulmonary disease and cardiovascular disease • Increased risk of cancer and cardiovascular disease with chronic exposure
LANDS AND ECOSYSTEMS	• Changing temperatures and snow conditions may impact recreational activities like skiing, skating, and canoeing • Sea level rise, ecosystem shifts, and permafrost thaw will damage places that are culturally significant • Shorter sea ice seasons, changing snow cover, and shifting wind patterns will impact travel conditions for Indigenous harvesters • Severe weather may damage crops and disrupt food supplies • Thawing permafrost and increased runoff could mobilize contaminants	• Increased risk of mental illnesses, including anxiety disorder, post-traumatic stress disorder (PTSD), and depression • Increased stress and uncertainty • Threatened water and food security, particularly for communities that rely on fish, wildlife, and traditional medicines
POPULATION DISPLACEMENT	• Sea level rise will make some coastal neighbourhoods in Canada uninhabitable • Increased risk of flooding and wildfires in some regions may cause people to move • Droughts, fire, and other climate hazards will likely increase global displacement	• Increased risk of mental illnesses, including anxiety disorder, PTSD, and depression • Increased stress and uncertainty • Risk of emerging and infectious disease as populations move and urban areas become denser
INFECTIOUS DISEASES AND PESTS	• Changing ecosystems shift where and when diseases and pests are a risk	• Changed exposure to infectious diseases • Threatened food security
EXTREME AND SEVERE WEATHER	• Severe weather-related disasters (including floods, wildfires, and tornadoes) will become more frequent and catastrophic in many regions	• Disrupted health services • Increased risk of injuries • Increased risk of mental illnesses, including anxiety disorder, PTSD, and depression

Social determinants of health

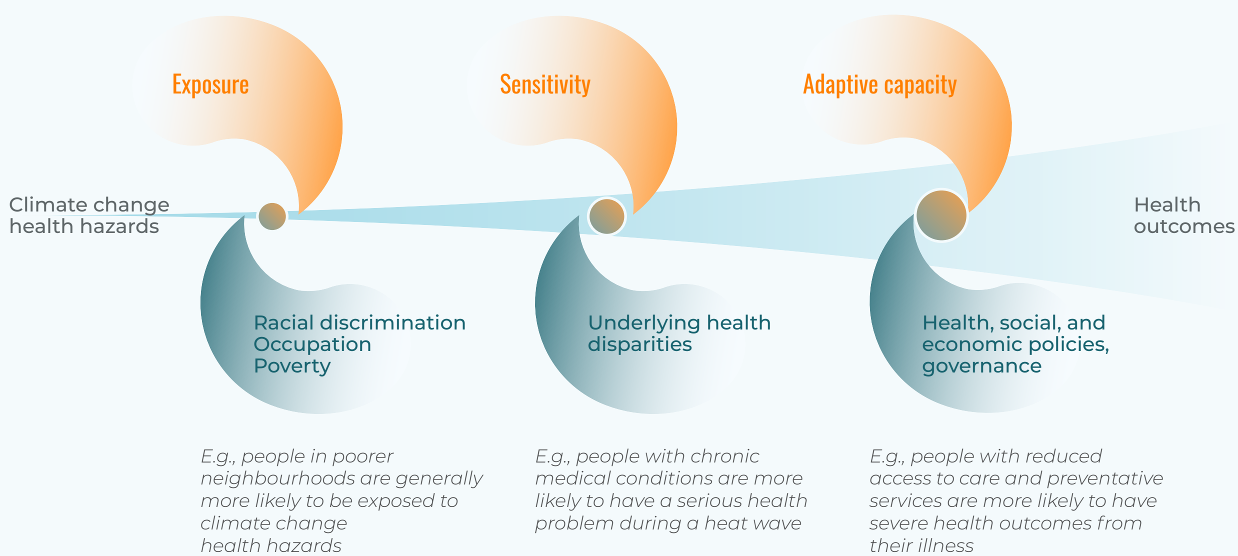
Canadian health outcomes related to climate change will depend on whether people are vulnerable to the climate hazards described above. In the context of climate change and health, vulnerability refers to the risk of negative health effects when impacted by a climate-related hazard (Adger et al., 2014). Vulnerability, in turn, is a function of three primary factors (Figure 2.1).

Each of these factors has social, economic, and geographic dimensions.

1. **EXPOSURE:** whether people are located where a climate-related health hazard occurs
2. **SENSITIVITY:** people's physiological predisposition to suffer a negative health outcome when exposed to a climate-related health hazard
3. **ADAPTIVE CAPACITY:** people's ability to avoid, prepare for, and cope with health impacts.

Figure 2.1

The intersection of social determinants of health and vulnerability influences how climate change affects health outcomes



Exposure to climate and environmental hazards varies across geography and between individuals

Not all people in Canada will be equally exposed to the health hazards linked to climate change. Climate change hazards are obviously different in Iqaluit than in Halifax, but exposure can also vary from neighbourhood to neighbourhood and even among individuals (Bélanger et al., 2014; Ebi & Hess, 2020; Ford et al., 2013).

Some communities in Canada are in areas that are naturally more prone to hazards linked to climate change. In some cases, the way communities were built has increased exposure to hazards. For example, urban areas covered by concrete with few trees can be up to 12 degrees Celsius warmer than surrounding areas in the summer (Sarofim et al., 2016). At the individual level, employment can also determine exposure. For example, forestry, agriculture, and construction workers are more likely to be exposed to extreme heat than an office worker.

Disadvantaged groups are often more likely to be exposed to climate change health hazards and experience their negative effects (Watts et al., 2015). People who are racialized and earn low incomes are more likely to live in areas prone to hazards that will be exacerbated by climate change, such as areas with poor air quality next to highways or hotter zones in urban areas. And people who are homeless or underhoused have far fewer options to escape climate-related health hazards like heat waves and flash floods.

Sensitivity to hazards is affected by social and economic conditions

People with underlying health conditions or people who are otherwise more physically vulnerable, like children or the elderly, are more likely to become sick, be unable to work, or die because of exposure to climate hazards. However, sensitivity to climate health risks is not just a function of age or genetics; sensitivity also reflects broader social and economic factors (Bresnahan et al., 2017; Lucyk & McLaren, 2017; Marmot, 2005). Disadvantaged groups are much more likely to have underlying health conditions that make them more likely to be affected by climate hazards.

In Canada today, for example, the average life expectancy of someone who did not graduate

from high school is 22 per cent shorter than someone with a university degree (PHAC, 2018). Infants are 1.5 times more likely to die in the first year of life if they are born into a low-income household compared to a high-income home (ibid). Black people in Canada experience higher rates of hypertension than white people, due in part to socioeconomic factors and stresses of racism and discrimination in everyday life (Veenstra & Patterson, 2016).

Health and social systems that help people adapt are not equally available to all Canadians

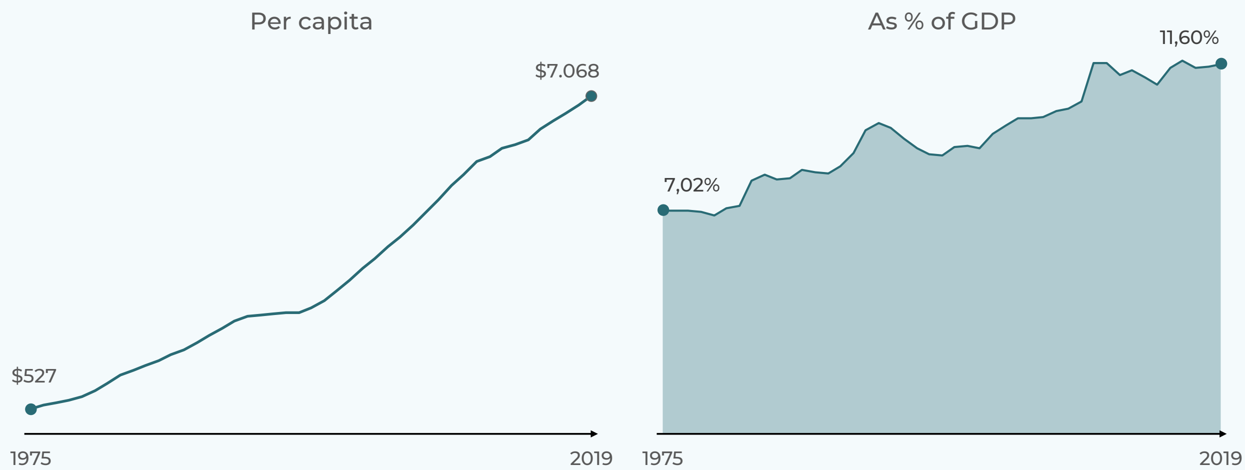
Public health and healthcare systems are some of the most important resources that help people adapt to climate-related hazards and other health threats. Public health helps people maintain good health and provides advance warnings of potential health threats, while healthcare systems provide the emergency, acute, and chronic treatment that people need if they become sick. However, as the COVID-19 pandemic has demonstrated, careful planning is needed to ensure critical resources are available in Canada when emergencies arise. Studies from Canada and other countries show increased rates of illness from climate change impacts could substantially increase the load on health systems, stretching budgets and increasing costs to governments and taxpayers (Burton et al., 2016; Limaye et al., 2019).

In 2019, the average cost of healthcare was $7,064 per person (CIHI, 2019). As Figure 2.2 shows, this average has been increasing steadily over the past 40 years because of Canada's aging population, increased life expectancy, and growing costs of healthcare delivery (PBO, 2017). Costs are already on an upward trajectory, and the added strain of health impacts linked to climate change will add to these costs—perhaps substantially. In Canada, approximately 70 per cent of medical costs are paid by governments, meaning that ultimately all taxpayers will feel the cost of climate change health impacts regardless of who is affected (CIHI, 2019). And the remaining costs will be passed on to the individuals who are affected , either directly or in the form of increased supplemental health insurance premiums.

Figure 2.2

Healthcare costs in Canada are rising (CIHI, 2019)

Healthcare costs in Canada (2019 $)



Not everyone in Canada benefits from the same access to and quality of healthcare. Out-of-pocket medical costs, wait times, and quality of care vary across the country (CIHI, 2021). Canada's size means that many communities are far from medical care. In the Northwest Territories, for example, 37 per cent of the population lives more than 100 km from a hospital. In Nunavut 79 per cent of the population lives more than 100 km from a hospital (Young et al., 2019). These barriers delay emergency treatment and access to specialists (Clark & Ford, 2017; Martin et al., 2018; OAG, 2017; Pong & Pitblado, 2005). The distances that individuals must travel for healthcare also hits government balance sheets and individual finances. The Government of Nunavut, for example, spends about 20 per cent of their health budget on aeromedical travel each year; per capita, Northern healthcare costs are twice as high as those in the south (Jong et al., 2019; Young et al., 2019).

Socioeconomic status also influences access to healthcare. Income and employment status are key factors in access to preventative health services and medications—approximately one in three working people in Canada do not have access to employer-based supplemental insurance for prescription medicines, mental health supports, or dental care (Guo et al., 2020; Martin et al., 2018). In about 25 per cent of households in Canada, someone is not taking a necessary medication because of an inability to pay (Angus Reid Institute, 2015). Women, youth, and low-income individuals are more likely to lack supplemental insurance, potentially worsening existing chronic disease burdens (Guo et al., 2020). Racial bias also affects access to and quality of care. Systemic racism in healthcare means that Indigenous, Black, and other racialized people in Canada can be less likely to have their health concerns taken seriously and to receive culturally appropriate care (Phillips-Beck et al., 2020).

Healthcare is not the only resource that people need in order to adapt and cope. Social and economic factors also determine other health inequities. Low-income, homeless, and underhoused individuals have less money to take action to protect themselves from climate-related health hazards. For example, finding alternative accommodation or sourcing food and clean water in the event of emergencies can be more difficult without economic resources. Further, current and historic policies, including colonialism and discrimination against newcomers, means that Indigenous and racialized groups are more likely to have lower incomes, be precariously employed, or experience homelessness—and as a result, have less access to adaptive resources (PHAC, 2018).

Adapting and preparing for climate change health impacts

No matter how the world reduces greenhouse gas emissions from this point forward, the effect of historic emissions means Canada will experience shifts in climate until at least the middle of the century. These changes and the hazards they create will persist for decades, if not centuries. Therefore, protecting health from climate change in Canada will mean more than reducing emissions. Supporting the health of people in Canada over the coming decades hinges on adapting and building resilience to threats that loom on the horizon.

Climate change *adaptation* refers to actions that help to prevent or reduce climate change impacts or that capitalize on any benefits of climate change (Adger et al., 2014; Smit et al., 2000; WHO, 2019). Adaptation actions can reduce exposure, decrease sensitivity, or increase adaptive capacity—or achieve any combination of these outcomes. Examples include building resources to respond to emergencies, strengthening infrastructure, and establishing government policies and programs that help individuals and businesses adapt (Adger, 2006; Watts et al., 2015).

Treat the symptoms and address the root causes

There are many types of climate change adaptation actions that can protect health. In this report we divide them into two groups and refer to the first as *treating symptoms*, meaning actions that are designed to prevent or reduce the negative impacts of specific health hazards related to climate change once they occur. The second, *addressing root causes*, refers to actions that tackle the underlying causes of climate health hazards and what makes people vulnerable to them.

The following health adaptation actions are examples of *treating symptoms* of climate change:

- Monitoring and early warning of health hazards, such as infectious diseases or heat and air quality risks
- Creating temporary shelters, such as cooling centres or clean air shelters, that protect people during dangerous weather- and climate-related conditions
- Increasing education and outreach programs that create community awareness and encourage household preparedness for specific climate-related health hazards
- Improving emergency response capacity of hospitals, first responders, and disaster organizations so they can better handle surges in demand

Actions to help *address root causes* of climate change health impacts include:

- Increasing access to health services including family doctors, medications, and public health resources—for disadvantaged individuals and communities to improve baseline health

- Reducing food and water insecurity—ensuring that food is affordable, nutritious, culturally appropriate, and readily available to all, regardless of location, income, or circumstance
- Increasing housing security and creating housing, including for seniors, that is affordable, safe, and culturally appropriate
- Undertaking community planning that eliminates or reduces climate health hazards, such as flood protection infrastructure and urban greening actions to reduce heat islands
- Reducing greenhouse gas emissions to minimize the degree of dangerous global and local climate change

Governance of adaptation policy is complex

As Table 2.3 illustrates, roles and responsibilities for health adaptation in Canada are complex, especially when it comes to addressing root causes. Doctors, social workers, and public health officials who generally have intimate knowledge of the health challenges of their communities are often disconnected from the policy levers that address the housing, socioeconomic, or healthcare access issues that make people sick (Austin et al., 2019; Awuor et al., 2020). Local governments and health authorities often lack the resources they need to implement health adaptations. Coordination on health adaptation between or within federal, provincial, Indigenous, and municipal governments is limited and knowledge is often not shared between jurisdictions (Austin et al., 2015, 2019; McKelvey & Heacock, 2017).

Table 2.2

Government roles in health adaptation

Health Adaptation Area	Healthcare	Emergency response	Senior support	Food and water security	Education and early childhood development	Poverty reduction and employment security	Housing security	Hazard early warning systems
Government departments and units implicated	health, veteran affairs, Indigenous services	health, defence, emergency management, health services	health, social services, long-term care	health, Indigenous services, agriculture, infrastructure	education, social services, youth, innovation/ science	social services, finance, innova-tion, industry	housing, finance, social services, Indigenous services	meteorological services, water resources, health, emergency management
Federal Role	veteran and Indigenous health, transfer payments	response and recovery funding	social secu-rity, transfer payments	social security, potable water infrastructure on reserve	taxation and transfer payments	industrial policy, taxation, social security, income security and CST	taxation, mone-tary policy, social housing	weather forecast-ing, coordination, standards
Provincial/ Territorial and Health Authority Role	health service delivery	public safety coordination and ambulance services	long-term care home regulation	social services	early childhood education	social services, taxation, indus-trial policy	social housing and land use planning	implementation of system
Indigenous Government Role*	public health programming		Elder services	harvester support	on-the-land programs	employment training and community supports		public awareness
Local/ Municipal Role	zoning and infrastructure	fire and police services	community programming	zoning policies, drinking water	community programming	promotion of local economy	land use plan-ning, social housing	watershed monitoring

* We have created this figure to illustrate the complexity and integration need; the diagram is not intended to be comprehensive. Roles and responsibilities will vary across the country. For example, depending on whether Indigenous governments operate under the Indian Act or self-governing agreements, roles and responsibilities will vary.

Canada has an adaptation policy deficit

Government policies and actions have not kept pace with the scale of emerging climate change risks to health and well-being (Austin et al., 2016; Ford et al., 2014; Labbé et al., 2017; OAG, 2018, Sawyer et al., 2020). Only $71 million has been earmarked in federal budgets since 2017 specifically for health adaptation programs—about three per cent of all funding explicitly linked to climate change adaptation and about 0.3 per cent of total climate change funding (Department of Finance Canada, 2019; Ness et al., 2020). While all types of health adaptation actions have been historically underdelivered, the need to address root causes has been especially overlooked.

Federal, provincial, and territorial government investments in health adaptation to date have been directed primarily to research and capacity building, with few actions that have tangibly reduced exposure or susceptibility to health hazards (Austin et al., 2015; ECCC, 2018b, 2019). In 2015, more than 80 per cent of federal government health adaptation initiatives involved information gathering and capacity building, while only 20 per cent involved implementing concrete actions (Austin et al., 2015), with little evidence to suggest that this balance has shifted since then. And while many health authorities in Canada's provinces and territories now acknowledge the importance of health adaptation, they are also lagging in the delivery of substantive actions (Berry, 2019)

Most federal, provincial, and territorial government efforts have also been narrowly focussed on adapting to specific hazards, notably heat and insect-borne diseases such as Lyme disease (ECCC, 2019). Other climate change health risks, such as effects on mental health and impacts from declining air quality in urban centres and areas affected by wildfires, could have economic and human costs that are equally if not more concerning. Yet little research or funding is currently focussed on addressing these emerging climate change health impacts. And with the exception of preliminary efforts to support the adaptive capacity of First Nations, Inuit and Métis communities (Richards et al., 2019), governments have not been prioritizing the root causes of health vulnerability—such as the effects of systemic racism and economic marginalization on health system access—in their health adaptation work.

Dylan Clark: Arviat, Nunavut

3 ANALYSIS: CLIMATE CHANGE IMPACTS AND COSTS

Our approach to characterizing the potential impacts and costs of climate change for Canada has two parts. First, we conducted quantitative analysis of the future impacts and costs of three major climate-related health risks: a) the impact of declining air quality associated with increasing ground-level ozone concentrations; b) increasing incidence of Lyme disease; and c) the health effects of hotter temperatures. A detailed description of our approach and complete results is published in a separate technical report (Boyd et al., 2020). Second, we reviewed and summarized the current understanding of other climate change health risks for Canada that are more difficult to quantify but still potentially harmful and costly.

Quantitative analysis

We chose to focus on air quality, Lyme disease, and heat because they are consistently identified as top health risks of climate change for Canada (BC Ministry of Environment and Climate Change Strategy, 2019; Berry et al., 2014; CCA, 2019). Further, because urban smog, insect-borne diseases, and heat waves have been impacting health in Canada and similar countries like the U.S. for generations, the science of these risks is well developed and can be applied to estimate future health impacts under climate change.

Calculating the extent to which climate change could influence these risks, impact health, and drive economic losses in Canada required three main steps:

1. Projecting future climate conditions across Canada
2. Modelling the connections between changing climate conditions, health hazards, and health outcomes
3. Calculating the economic impact of changes in health outcomes induced by climate change

Projecting future climate

To model the links between climate and health impacts, we first need to understand what Canada's future climate will look like. Climate change impact studies usually draw on models that project future shifts in the global climate caused by greenhouse gas emissions. Climate change models do not give a single picture of the future climate under increasing global greenhouse gas emissions but a spread of possible changes.

Models consider multiple scenarios for two reasons. First, the world's leading climate research centres have developed climate models that represent the complexity of the global climate system in different ways, and therefore they produce different results. Second, since future global greenhouse gas emissions and concentrations of these gases in the atmosphere depend on many societal choices yet to be made, each climate model simulates multiple emissions and concentration pathways to represent a range of possible decisions and outcomes.

While there are over 20 global climate models (GCMs) available, we chose a subset of seven that captured most of the range of climate possibilities for Canada to keep the total number of modelling scenarios manageable. We obtained model data with help from Environment and Climate Change Canada's Canadian Centre for Climate Services, drawing on datasets developed for Canada by the Pacific Climate Impacts Consortium.[1] These climate datasets are large, with projections of precipitation and temperature for every day from 2041 to 2100 on a grid approximately 10km by 10km covering all of Canada.

We also considered two different concentration pathways (IPCC, 2013) (Figure 3.1). One path is a moderate greenhouse gas concentration scenario (RCP 4.5)—referred to as the low-emissions scenario in this report—which represents a world in which concerted action is taken to reduce greenhouse gas emissions by the middle of the current century. This scenario is projected to result in a global temperature increase of around 2.5 degrees Celsius by 2100 and is what most experts consider to now be the most realistic scenario of curbing global warming. However, given the possibility that global emissions may not be effectively reduced, we also examine costs and losses associated with a high greenhouse gas concentration scenario (RCP 8.5), known as the high-emissions scenario. This scenario represents the outcome of continued growth in emissions for the remainder of the century, resulting in about 4.5 degrees of global warming.

Finally, for each combination of climate model and concentration scenario, we analyzed impacts and costs for two future time horizons: the middle of the century (2041 to 2070), which we refer to as "the 2050s," and the end of the century (2071 to 2100), which we refer to as "the 2080s." The 2050s analyses provide a sense of the type of medium-term impacts Canada is likely to experience, while the 2080s analyses show how impacts may accelerate, plateau, or decline over the remainder of the century. The analysis of 30-year time periods is common in climate change impact assessments, as they average out short-term variability in the climate so that trends can be more clearly seen (IPCC, 2013).

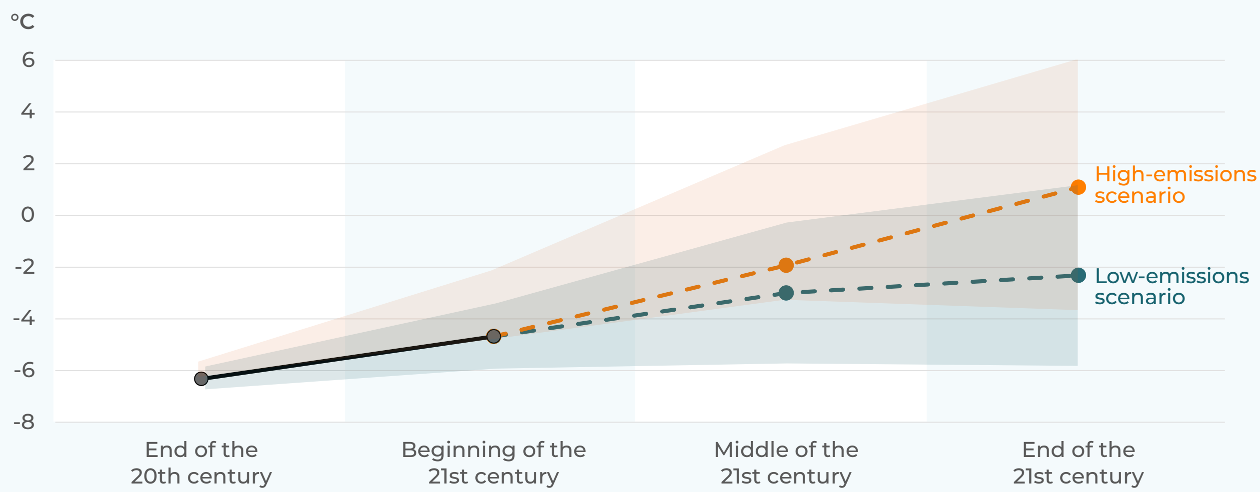
As a result, we modelled 28 scenarios of health impacts—permutations of seven climate models, two emissions scenarios, and two time periods. Our modelling included all of Canada, examining future patterns down to daily time frames with a spatial resolution as fine as individual cities and towns.

[1] https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

Figure 3.1

Temperatures in Canada will rise for the remainder of the century

Projected average annual mean daily temperature for Canada



By 2100, the average annual daily temperature for Canada is projected to increase by approximately two degrees Celsius to six degrees Celsius compared to the baseline average, depending on global emissions.

Modelling connections between climate and health outcomes

To model impacts induced by expected changes in Canada's climate, we first estimated future health hazards. In the case of heat, this was straightforward, as climate models produce direct projections of future temperature. For air quality, this required estimating future concentrations of ground-level ozone—our air pollutant of focus—using temperature projections and the relationship between temperature and ground-level ozone. For Lyme disease, it required estimating future incidence based on an understanding of the connection between incidence and temperature.

Once future hazards were established, we drew on established research to develop specific *exposure-response functions*. Exposure-response functions are based on past studies of the health outcomes from exposure to different health hazards in large populations. Using these exposure-response functions for ground-level ozone, Lyme disease, and hot temperatures, we estimated the potential for illness, or *morbidity*, and premature death, or *mortality*, associated with those health hazards under climate change.

To estimate future health outcomes under climate change, we also needed to consider future changes in Canada's population, as a growing population with shifting age demographics will respond differently to health hazards. We used future population and age group estimates from Statistics Canada, which provides projections up to 2068 (Statistics Canada, 2019), and then we extended these trends to 2100. Because of the nature of the models we used, our ground-level ozone analysis reflected the effect of an aging population, but our analyses of heat and Lyme disease reflected total population growth only.

We showed the degree to which climate change was responsible for future health impacts in our estimates by also estimating what the health impacts would have been for Canada's population in the 2050s and 2080s in the absence of climate change. To do this, we ran our models using 2050s and 2080s population projections and climate data from the 1971 to 2000 period. This period is frequently used as the 30-year baseline in climate change impact assessments that look at 30-year projections for the 2050s and 2080s time frames (Charron, 2016). The Canadian Centre for Climate Services was able to provide us with datasets from this period on the same 10 x 10 km grid as the climate model projections, allowing precise comparison. In some cases, we were also able to use this data and our exposure-response functions to calculate health impacts for the current Canadian population. This provided another useful basis of comparison with our future estimates, as long-term measurements of past illness and death associated with ground-level ozone, Lyme disease, and heat are not available.

The following sections go into additional detail on our modelling, including how we examined the benefits of certain health adaptation actions for heat.

Climate change exacerbates local air quality risks

Air pollution contributes to approximately 14,600 premature deaths in Canada every year and makes tens of thousands ill through respiratory and cardiac illnesses and other diseases (Health Canada, 2019). Air pollutants that cause these effects include fine particles and chemical toxins from sources like industrial emissions; vehicle exhaust; electricity generation and home heating powered by coal, oil, or gas; and smoke from wildfires.

Our analysis focusses on ground-level ozone. Although ozone naturally and safely occurs in the upper atmosphere, it can also form at ground level from the interaction of sunlight, warm temperatures, exhaust from vehicles, and other fossil fuel combustion. In this form, it is a major component of urban smog. Ground-level ozone can irritate lungs and airways, aggravating respiratory

illnesses, coronary vascular disease, and asthma and increasing risk of pregnancy complications. Studies have found significant increases in emergency department visits and deaths during and shortly after days with high ground-level ozone concentrations (Cakmak et al., 2016; Leung et al., 2020). Further, long-term exposure to ground-level ozone may elevate an individual's risk of respiratory and cardiovascular illnesses later in life (Atkinson et al., 2016).

We chose to analyze the health effects of changing ground-level ozone concentrations because these are strongly linked to temperature and are thus expected to increase with climate change (Watts et al., 2015). Drawing on known relationships between temperature and ozone, we can forecast future ozone concentrations based on projected changes in temperature across Canada (Boyd et al., 2020). To model how changing ground-level ozone concentration could affect health, we use Health Canada's *Air Quality Benefits Assessment Tool (AQBAT 3.0)* to assess changes in illness, healthcare demands, and deaths related to air quality. AQBAT is an application that allows the user to model changes in air quality and the resulting health impacts by defining various parameters, such as pollutants and demographic estimates. We used AQBAT to estimate three key health morbidity outcomes associated with ground-level ozone: asthma symptom days, acute respiratory symptom days, and respiratory emergency room visits.[2]

Climate change will negatively affect air quality in more ways than just through ground-level ozone. Another major climate-related air quality health hazard is the increasing size and frequency of wildfires, particularly in Western Canada, where smoke will affect air quality in many communities more frequently during summer months. Higher pollen concentrations could also lead to surges of allergies, respiratory illness, and respiratory emergencies (Harun et al., 2019; Thien et al., 2018). The true scale of climate-induced air quality health impacts will be substantially larger than those we modelled for ground-level ozone, as these other impacts are still difficult to model accurately.

Rising temperatures are expected to enable the spread of Lyme disease

Lyme disease is caused by infection with the bacterium *Borrelia burgdorferi* from the bite of an infected tick. Most people with Lyme disease experience minor symptoms, including rash, fevers, heart arrythmias, and joint pain. All these symptoms usually fully resolve with antibiotics (Shapiro, 2014). However, if Lyme disease is not detected and treated early, it can cause severe and lifelong health problems. Over the past decade, Lyme disease in Canada has been most prevalent in Quebec and Ontario, where an average of about 4.5 people per 100,000 are diagnosed each year (INSPQ, 2018; Public Health Ontario, 2020a).

Lyme disease is one of many infectious diseases whose distribution and incidence will shift as climate change alters the range and life cycle of the insects and animals that transmit the disease and as shifts in ecosystems disrupt balances that have historically kept diseases and transmission in check (Ogden & Gachon, 2019). Lyme disease has been the focus of much discussion in the context of the health impacts of climate change in Canada, as it was virtually unheard prior to the 1990s (Bouchard et al., 2019; Ogden et al., 2009) but has now spread to at least six provinces as a result of a changing climate (Health Canada, 2020).

[2] Asthma symptom days and acute respiratory symptom days count the number of days that one person experiences symptoms, such as coughing or shortness of breath. Asthma symptom days only apply to asthmatic children aged 5 to 19, while acute respiratory symptom days apply to the entire adult population and non-asthmatic children. Respiratory emergency room visits include the entire population. See Health Canada AQBAT for full definition.

While there is still uncertainty about how climate change may affect the future spread and incidence of Lyme disease, data and tools exist to begin to estimate potential impacts and costs (Clow et al., 2016, 2017; Gasmi et al., 2017; Ogden, 2008; Ogden et al., 2005). We drew on research that modelled the link between Lyme disease and changing temperatures to estimate the future incidence of Lyme disease infections in Canada and their costs (Dumic & Severnini, 2018).

Heat and hot weather increase illness and death and undermine productivity

When temperatures rise beyond what individuals can physiologically withstand, risk of illness and death increase rapidly from conditions such as heat stroke, as well as from increased risk of heart attack, stroke, and other forms of cardiovascular disease. In most cases, individuals who experience heat-related complications have underlying health conditions, such as cardiovascular disease, high blood pressure, diabetes, or respiratory diseases. Heat-related complications are also more likely to affect individuals who are not able to escape exposure to heat because of jobs that require them to be outside or a lack of adequate housing and access to green space.

Recent heat waves in Canada have been deadly. For example, in Vancouver in 2009 an estimated 72 deaths occurred over a two-week period (Ho et al., 2017; Stewart et al., 2017). A Montreal heat wave in 2018 killed 66 people (Santé Montréal, 2019).

Climate change has the potential to substantially increase heat-related illness and death in Canada. Canada's climate is warming almost twice as fast as the global average: between 1948 and 2016, the average annual temperature increased by 1.7 degrees Celsius (Bush & Lemmen, 2019). And some parts of Canada are seeing even more extreme warming; Northern Canada has seen an increase of 2.3 degrees over that time—more than triple that of Atlantic Canada (Bush & Lemmen, 2019). Across Canada, summer nighttime temperatures are warming at a quicker rate than summer daytime temperatures in many locations (Vincent et al., 2018), which is important because hot nights further increase the risk of illness and death (Murage et al., 2017).

To model how climate change could affect heat-related illness and death, we looked at the research linking temperature and illness. Specifically, we drew from Canadian studies that analyzed regional relationships between high-temperature days and health outcomes to develop exposure-response functions and calculate health outcomes—both morbidity and mortality (Boyd et al., 2020).

When assessing heat-related mortality, we considered both displaced and premature deaths. *Displaced deaths* refer to acute deaths that occur during a heat episode and concern people at the end of their lives who would have died within a few weeks even without heat exposure. *Premature deaths* refer to heat-related deaths in otherwise healthy individuals who die much earlier because of heat exposure. Premature death implies that an individual could have lived and worked longer, and the cost of their death is calculated differently, as described below.

Hot weather also affects economic output by reducing labour productivity, particularly for jobs that take place outside or in indoor spaces without proper climate control (Flouris et al., 2018; Orlov et al., 2020). We assessed how hot weather may affect labour productivity using exposure-response functions based on analysis of historic lost work time for sectors and professions that are vulnerable to heat (Zivin & Neidell, 2014).

Cold-related health impacts

At first glance, it seems that if a warming climate increases heat-related health impacts and deaths it should also reduce cold-related health impacts—but it is not that straightforward (Åström et al., 2018; Barnett et al., 2012; Ebi & Mills, 2013; Kinney et al., 2015). In a study of 26 U.S. and three French cities, increased deaths during winter months were not primarily driven by colder temperatures but rather other seasonal factors, such as influenza (Kinney et al., 2015). Additionally, extensive literature reviews have concluded that the association between temperature and higher rates of mortality in the winter is relatively weak (Barnett et al., 2012; Ebi & Mills, 2013).

Considering the uncertainty of the current science, we have not tried to estimate the effects of climate change on cold-related mortality and morbidity in this study. Other national-level assessments of health impacts and costs have made similar decisions (Boyd et al., 2020).

Costing climate impacts

Our modelling analysis looks at three types of costs. We estimate costs associated with the use of healthcare services, costs from losses in labour productivity, and the costs of lost life and quality of life. All costs are reflected in 2019 Canadian dollars in our analysis. We discounted future costs for some calculations, such as cost-benefit analyses, using a real rate of three per cent (Boyd et al., 2020).

Healthcare costs include the costs of medical care, treatment, and drugs. To estimate the costs of specific illnesses, we used the Public Health Agency of Canada's cost-of-illness database, which includes data on the average costs of hospital care, physician care, and drugs for all major types of illness and injury (Boyd et al., 2020).

Productivity costs are the value of lost productivity when people are unable to work and participate in other activities because of environmental conditions, illness, or premature death.

We estimate:

- costs to individuals of missed or less efficient work based on the cost of the total work hours lost at current wages;
- costs to the broader economy in terms of reduced economic value generated for the total number hours that are worked;
- costs of lost work time due to illness based on the length of hospital stays associated with the types of illness we examined multiplied by average salary rates;
- productivity costs of premature death by assessing the loss of an affected individual's lifetime working income.

Costs of lost life and lost quality of life reflect the value that society places on avoiding ill health or premature death. Avoiding deaths won't directly put more money in bank accounts and government treasuries. But putting a dollar sign to death does show how much people in Canada value reducing the risk that they or their loved ones will die prematurely from heat-related illness. Governments often use the "value of statistical life" (VSL) to estimate the societal benefits of policies that are expected to reduce the risk of premature death; VSL indicates how much people are willing to pay to reduce this risk. We used the VSL for Canada recommended by the Treasury Board Secretariat, adjusted to approximately $8 million in 2019 Canadian dollars to reflect inflation (Chestnut & De Civita, 2009). We used this value to estimate the value of each premature and displaced death, with the VSL adjusted to reflect the number of life years that would be lost. We also used an adjusted VSL to calculate the value of lost quality of life for extended illness from Lyme disease, but we were unable to do so for heat-related illness because our models could not predict the length of illness (Boyd et al., 2020). AQBAT uses research on willingness to pay to avoid specific health impacts related to air quality to directly calculate the value of ill-health outcomes.

When reporting our results, we show the range of estimates reflecting the 28 combinations of climate models, emissions scenarios, and time frames. For some analyses we include additional variable factors that create even more scenarios. We illustrate the range of outcomes in graphs, while discussing the average estimates of the seven climate models in the text.

Assessing other potential health impacts

Air quality, Lyme disease, and heat are only a small sample of the possible effects of climate change on health in Canada. Many other potential impacts call for attention but are not currently possible or appropriate to quantify.

We should not ignore important health impacts that we cannot model or quantify, just as we cannot wait to prepare and adapt to minimize those impacts even if we do not completely understand them. Therefore, to help paint a broader picture of climate-related health impacts that should be part of the adaptation discussion in Canada, we draw on existing research, literature, and knowledge to highlight the potential effects of climate change on:

- Increased susceptibility to mental illnesses and effects on mental health and well-being
- Impacts to food security, identity, and well-being, particularly in Indigenous communities
- Threats to healthcare infrastructure and potential for disruption of critical services

ESTIMATING HEALTH COSTS OF CLIMATE CHANGE FOR CANADA

This section presents our estimates of health impacts and costs for heat and air quality in Canada's changing climate. We present projected morbidity and mortality outcomes, healthcare costs, the value of lost life, and lost quality of life for low and high greenhouse gas emissions scenarios for both the 2050s (period from 2041 to 2070) and 2080s (period from 2071 to 2100) We also present the projected productivity loss of labour hours and associated costs due to the impacts of heat on health. And we assess two adaptation scenarios that can reduce heat exposure and illustrate their costs and benefits.

In order to articulate the potential magnitude of costs more clearly, we describe "average" values for each impact and scenario throughout this section. However, the average value does not capture the uncertainty or the worst-case scenario. We present the broader range of potential outcomes in graphs throughout the section. In our figures, each line reflects the change projected under one global climate model. Blue bars reflect the change modeled under a low-emissions scenario. The orange lines reflect a high-emissions scenario. Therefore, the range between the lines in each graph reflects possible outcomes for each emissions scenario.

Costs of ground-level ozone impacts on health

Ground-level ozone concentrations could increase substantially as temperatures rise, affecting air quality, undermining health and well-being, and imposing costs on the Canadian economy.

Climate change will increase illnesses and deaths from ground-level ozone across the country

As temperatures increase, ground-level ozone concentrations will increase across Canada. Our models show that, with the temperatures projected for the 2080s, the average summer urban ozone concentration may increase 22 per cent from the baseline of 38 parts per billion (ppb) to 49 ppb under the low-emissions scenario and by 47 per cent to 56 ppb under the high-emissions scenario. These levels would approach those currently experienced in Southern California, which consistently has the worst air quality in North America (Metropolitan Transportation Commission, 2017).

Figure 4.1 shows the combined annual healthcare costs of these three respiratory illnesses. Of the three respiratory impacts modelled here, acute respiratory symptom days (days a person experiences shortness of breath related to air quality) are projected to be the most expensive, making up about 77 per cent of the costs. Asthma symptom days comprise about 16 per cent of costs, and respiratory emergency room visits make up the remaining seven per cent.

The healthcare costs of ozone exposure are comparable to those of other high-priority illnesses. For example, the annual healthcare costs of cancer have been estimated between $3.5 and $7.5 billion (de Oliveira et al., 2018; PHAC, 2010). In the high-emissions scenario, by the end of the century the healthcare costs of ozone exposure could total the equivalent of one quarter of current healthcare costs linked to cancer. Reducing local carbon emissions, such as those emitted by vehicles or industry, could reduce the formation of ground-level ozone and significantly reduce health costs.

Figure 4.1

Increasing ground-level ozone from climate change will grow healthcare costs

Projected annual healthcare costs of illnesses related to ground-level ozone

Due to temperature rise, ground-level ozone is projected to increase in the coming decades unless action is taken. We estimate the increase in ground-level ozone will result in additional healthcare costs, although actions to reduce emissions could reduce costs.

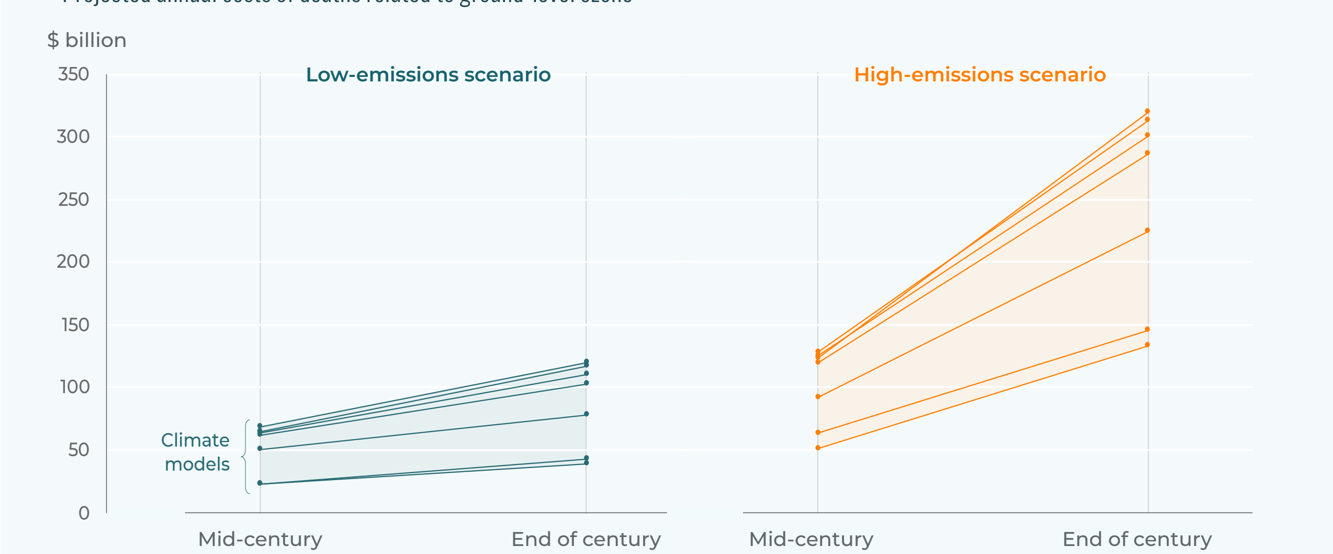
As temperatures increase, our calculations show that excess deaths associated with ozone exposure increase. Over a period of 10 years, we estimate that ozone-linked respiratory illnesses are associated with 270,000 hospitalizations or premature deaths—more than the population of Gatineau, Quebec.

While healthcare costs from ozone exposure could be costly, the indirect costs of deaths and suffering represent a much more expensive and under-appreciated cost of climate change. As Figure 4.2 shows, ground-level ozone mortality costs are much greater than the costs we modelled for heat-related deaths. Without global mitigation, heat-related deaths are projected to cost $8.5 billion annually by the 2080s, while deaths from ozone exposure represent a cost of $246 billion. Costs are double current amounts under the high-emissions scenario at mid-century, and by the end of the century, almost triple.

Figure 4.2

Costs of premature deaths from ground-level ozone could exceed $300B by 2080

Projected annual costs of deaths related to ground-level ozone



Urban air pollution disproportionately harms disadvantaged groups

Most of the health impacts described here will be concentrated in urban areas, based on the current and future projected ozone distribution. According to recent data, urban areas in Ontario have the highest ground-level ozone concentrations: London (41.5 ppb), Niagara (40.0 ppb), and Windsor (39.5 ppb) top the list nationally (ECCC, 2018a).[3] Rural and remote communities typically have low ground-level ozone concentrations, although local industrial activities and wood heating affect exposure. Disadvantaged populations can experience higher incidence rates of diseases that can increase complications of air pollution, with evidence that risk of death from fine particulate matter is correlated with education and income (Christidis, 2019). Asthma complications have been shown to disproportionately affect low-income and racialized populations (Beck et al., 2014). National data from 2008 to 2010 shows that the prevalence of asthma among First Nations and Métis adults was, for both populations, 1.6 times the prevalence among non-Indigenous adults (PHAC, 2018). Among children from birth to age nine, asthma hospitalization rates nationally are 1.5 times higher in the lowest-income neighbourhoods compared to the highest-income neighbourhoods (CIHI, 2018).

Regions with older populations will see higher death rates

Regions of Canada with older populations will see an increase in rates of disease and mortality. The Atlantic provinces show particularly high mortality rates under all four scenarios, even though ozone concentrations are projected to increase most in other places like Ontario and Quebec. This high mortality rate may be explained by the projected future demographics of the Atlantic provinces (Boyd et al., 2020).

[3] Average annual concentration from 2002–2016 based on census metropolitan areas.

Wildfire impacts on health

From aggravating asthma to mental health impacts from the loss of homes and livelihoods, wildfires can have a major impact on health. A recent study estimated that the cost of health impacts from wildfire smoke in Canada between 2013 and 2018 (not including 2016, the year of the Fort McMurray wildfire, because of data problems) ranged from $4.7 billion to $20.8 billion per year (Matz et al., 2020). Climate change has already increased the frequency and severity of wildfires across the country (Tan et al., 2019), and this trend is expected to continue, indicating that there are growing health impacts on the horizon (Sun et al., 2019; Wang et al., 2020; Wotton et al., 2017).

Wildfire impacts on human health

There have been numerous destructive and record-setting wildfire seasons recently across Canada. In 2016, a fire near Fort McMurray, Alberta, drove over 80,000 people from their homes across the region and produced smoke that affected much of Western Canada and the northwestern United States. A year later, wildfires in British Columbia burned over 1.3 per cent of the province's land area and led to over 65,000 evacuations. These and other fires can have significant impacts on people's health, including the following examples.

- *Respiratory impacts:* Wildfire smoke is composed of fine particulate matter and toxic gases. Exposure can worsen pre-existing health conditions, including asthma and chronic obstructive pulmonary disease (COPD), and there is mixed evidence of increased risk of cardiovascular diseases. Effects from smoke exposure can range from shortness of breath and use of outpatient medical resources to hospitalization and death (Liu et al., 2015; Reid et al., 2016).
- *Mental health:* Disasters and associated threats to health, well-being, and livelihoods are often traumatic. Wildfires can destroy personal possessions, transform cherished places and ecosystems, and threaten economic security. These effects have been linked to post-traumatic stress disorder (PTSD), depression, anxiety, and, in some cases, suicidal thoughts (Brown et al., 2019; Dodd et al., 2018; Hayes et al., 2019). Smoke and changes to the environment can also impact broader well-being; one study found that reduced visibility from smoke across the B.C. Lower Mainland was equivalent to between $1 million and $62 million per year in economic welfare losses (Haider et al., 2019).
- *Injury and death:* Falling trees, emergency evacuations and response, and exposure to flames and heat can lead to burns, physical trauma, motor vehicle crashes, and asphyxiation. There is growing evidence that some disasters, including wildfires, increase risk of assault and intimate partner violence (Bell & Folkerth, 2016; Gearhart et al., 2018; Rao, 2020).
- *Food and water security:* The devastation of landscapes and ecosystems by wildfire can contaminate drinking water sources and harm wild plants and animals that some communities rely on for food (Dodd et al., 2018; Robinne et al., 2019).
- *Compounded impacts:* Health impacts are compounded for communities that routinely experience wildfires. Twenty-nine per cent of communities that were evacuated due to wildfires between 1980 and 2007 had been evacuated at least once before during the same time period, some even during the same year (Beverly & Bothwell, 2011). Besides exposing residents to the effects of smoke or injury, repeat wildfires and evacuations are destabilizing and disruptive to communities.

Lyme disease

Under a low-emissions future, projected additional cases of Lyme disease due to demographic change and climate change amount to about 8,500 annually by mid-century and 9,900 by the end of the century. This represents a rate of about 17.8 annually per 100,000 by mid-century and 18.2 annually by end of century. The rates are lower under the high-emissions scenario than under the low-emissions scenario because the research from the United States that we used for our modelling observed that Lyme disease incidence decreases above a certain temperature. However, it is unclear if the same pattern would occur in Canada. Despite this uncertainty, the figures represent a substantial increase: Lyme disease incidence rates were 2.7 per 100,000 nationally in 2016 and averaged 1.4 per 100,000 between 2009 and 2016 (PHAC, 2020).

Figure 4.3 shows the projected total costs of Lyme disease, comprising both healthcare costs and costs of lost quality of life. Lyme disease does not often result in death, so most of the costs come from lost quality of life as a result of illness. In both low- and high-emissions scenarios, these costs make up about 97 per cent of projected costs, while healthcare costs make up only about three per cent.

Lyme disease is projected to be the least costly of the health impacts we modelled. Under the low-emissions scenario, healthcare costs of acute respiratory symptom days alone could total $210 million annually by mid-century, while healthcare costs of Lyme disease are only $3 million annually. Similarly, costs of heat-related healthcare are modelled to be much greater than Lyme disease, totalling $100 million by mid-century.

Costs of illness from heat and hot weather

Heat-related health impacts are already a climate-related threat to the well-being of Canadians. Increasing warming will worsen this risk, with significant economic implications.

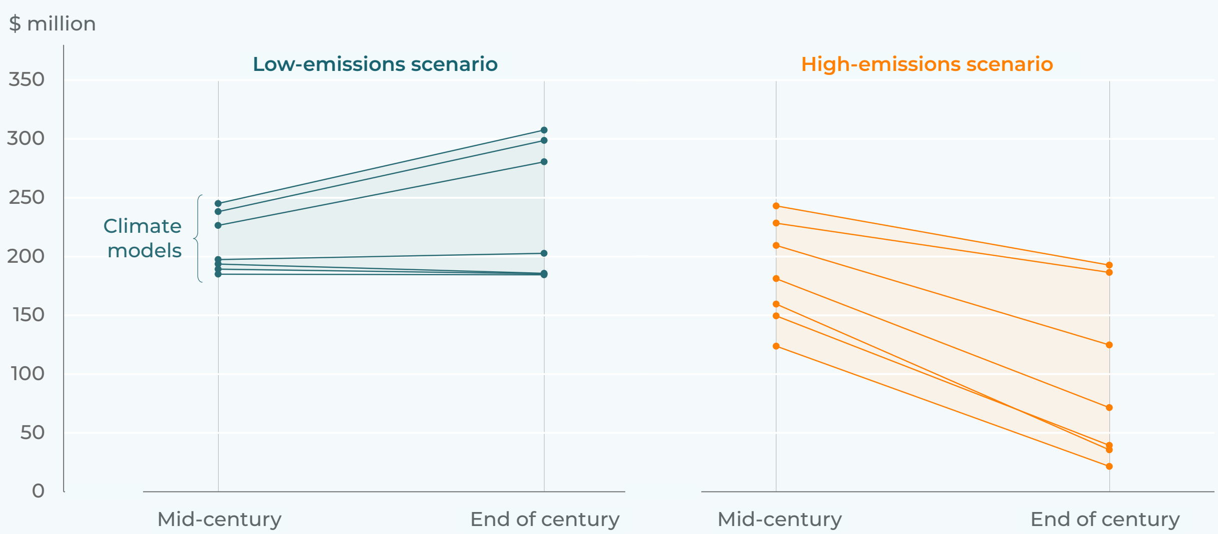
Climate change will increase the frequency of potentially deadly hot days

As the climate warms, the number of days when temperatures reach levels where heat-related deaths begin to occur is going to increase. These temperature thresholds are determined for major

Figure 4.3

Estimated costs of healthcare and lost quality of life from Lyme disease

Projected annual Lyme disease costs for healthcare and lost quality of life



Canadian cities and are based on analysis of historic mortality data to define the temperature at which deaths begin to increase. We use these thresholds to estimate future mortality rates associated with warming temperatures.

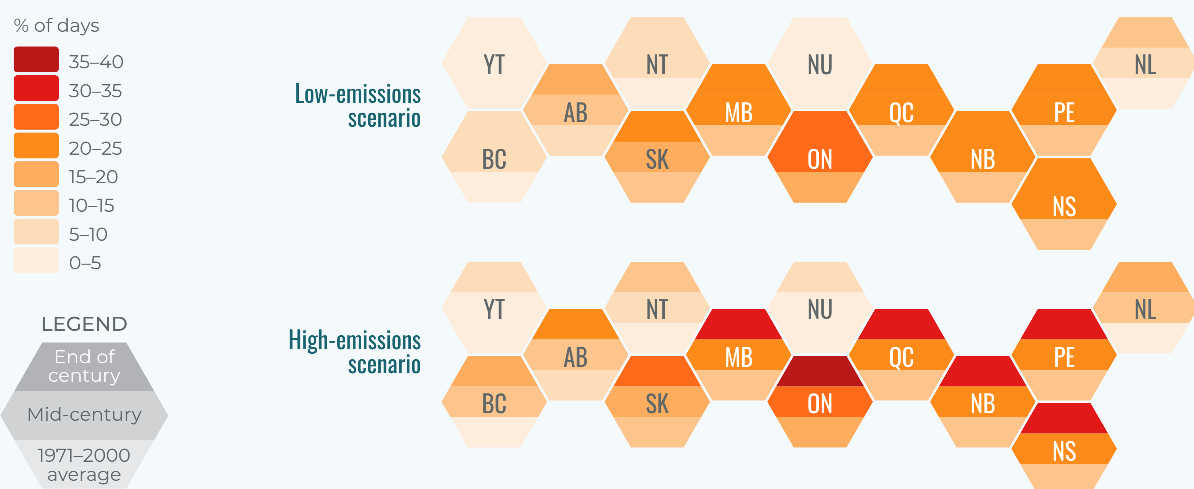
Between 1971 and 2000, Ontario and Manitoba had an average of about 50 days per year with temperatures above thresholds for heat-related deaths, and Yukon had an average of one day per year. In the 2050s—when children born today are 30 years old—the number of days above thresholds will increase by 1.5 times in Ontario and Manitoba and more than six times in Yukon. By the 2080s, the average number of days above thresholds across Canada will range from 75 days each year in the low-emissions scenario to 100 days each year if emissions go unchecked: an increase of two to 2.5 times the 1970–2000 baseline.

By province and territory, there is more variation: as Figure 4.4 illustrates, Ontario, Quebec, Manitoba, and the Atlantic provinces are projected to have the highest number of potentially deadly hot days annually. However, given that Northern Canada is experiencing more rapid temperature increases compared to the rest of Canada, Nunavut, Yukon, and the Northwest Territories are projected to see the greatest amount of change in days above thresholds for heat-related deaths over the coming decades. Compared to a scenario without climate change, we project the number of days above these thresholds will increase by a multiple of three to 10 in the territories over the next 30 years, with the largest increases in Yukon and Nunavut. In British Columbia and Newfoundland and Labrador, where days with heat that can cause premature death have also historically been rare, we model a twofold to threefold increase over the next 30 years.

Figure 4.4

The number of days where heat can cause premature death will increase across Canada

Percentage of days in the year over heat danger thresholds



Climate change will increase heat-related hospitalization and healthcare costs

Climate change will increase heat-related illness and hospitalization across Canada. We estimated the change in hospitalizations from four diseases: coronary heart disease, stroke, hypertensive disease, and diabetes, all of which have a strong relationship with temperature. Figure 4.5 shows the projections for hospital visits nationally.

These increases in hospitalizations will mean substantial healthcare system costs. Even under the low-emissions scenario, heat-related hospitalization rates represent a 21 per cent increase by mid-century and a 102 per cent increase by the end of the century as compared to current average rates.

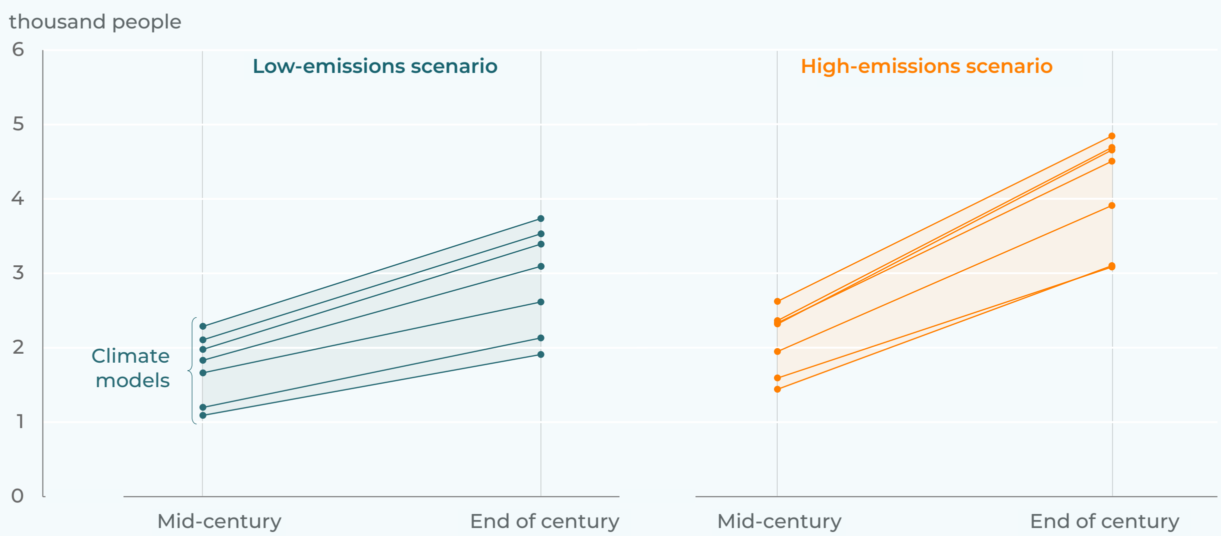
We project that the greatest impacts in absolute and per capita terms will occur in Ontario and Quebec, both because of their larger populations and because they will experience a greater temperature increase in the areas where most of their population lives.

While some increases in heat-related hospitalizations would be expected due to growing populations, projected hospitalizations due to climate change generally far exceed the increases from population growth alone. For example, without climate change, British Columbia would be expected to see an additional 10 heat-related hospital visits per year in 2080, based simply on population growth. However, this number increases to 50 under the low-emissions scenario and 80 under the high-emissions scenario.

Figure 4.5

Hotter days mean more hospital visits

Projected annual heat-related hospitalizations



Heat impacts will undermine labour productivity

Rising temperatures are projected to have a large negative impact on working hours, especially in economic sectors where a great deal of work takes place outdoors or in poorly cooled spaces. This includes manufacturing, quarrying, oil and gas extraction, utilities, transportation, forestry and fisheries, and construction.

Of the high-risk sectors our modelling examines (Figure 4.6), productivity losses will be highest in the manufacturing sector primarily because manufacturing represents a larger relative share of national employment than other high-risk sectors. Productivity losses from the manufacturing, transportation, and warehousing sectors could also impact supply chains, creating a ripple effect in other sectors that is not reflected in our analysis.

Under the high-emissions scenario, climate change will lead to a projected loss of 128 million hours annually by end of century. This is the equivalent of 62,000 full time workers, representing lost productivity of $14.8 billion annually. Labour productivity losses are much smaller under the low-emissions scenario, with 57 million labour hours across these high-risk industries lost annually by the 2080s—less than half the projected loss in the high-emissions scenario—with a cost of $6.7 billion.

Figure 4.6

Climate change will reduce productivity in high-risk sectors

Projected annual labour productivity change

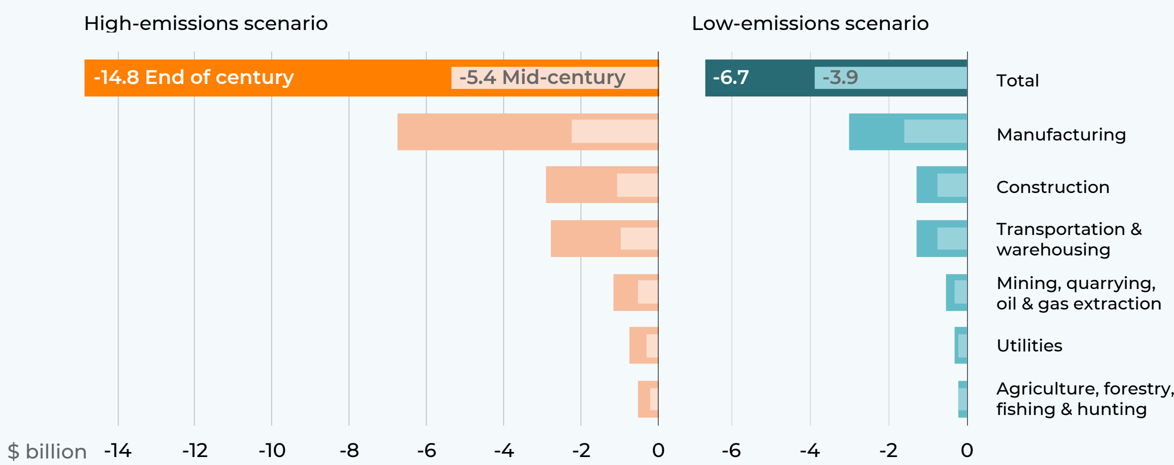
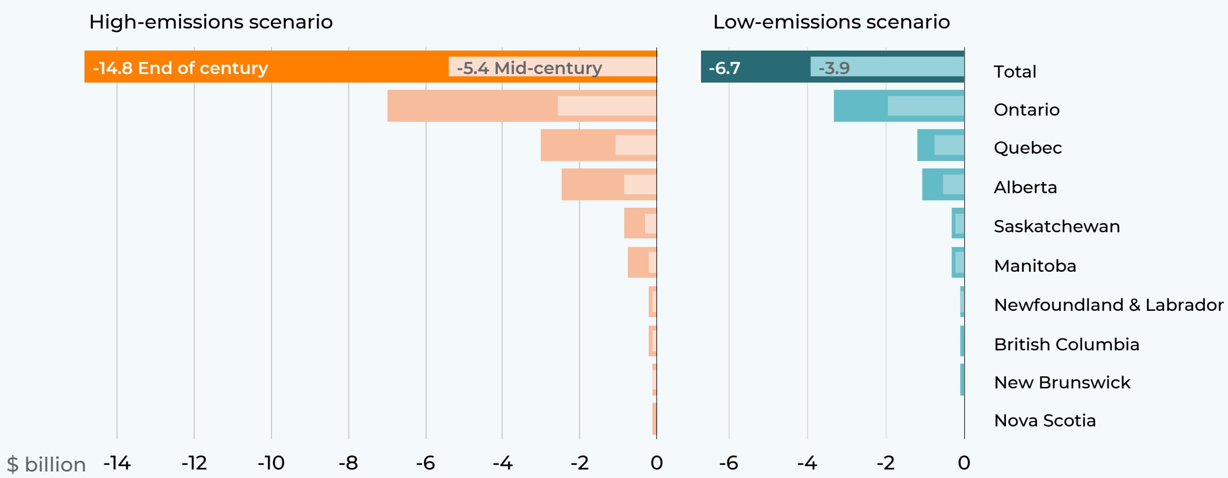


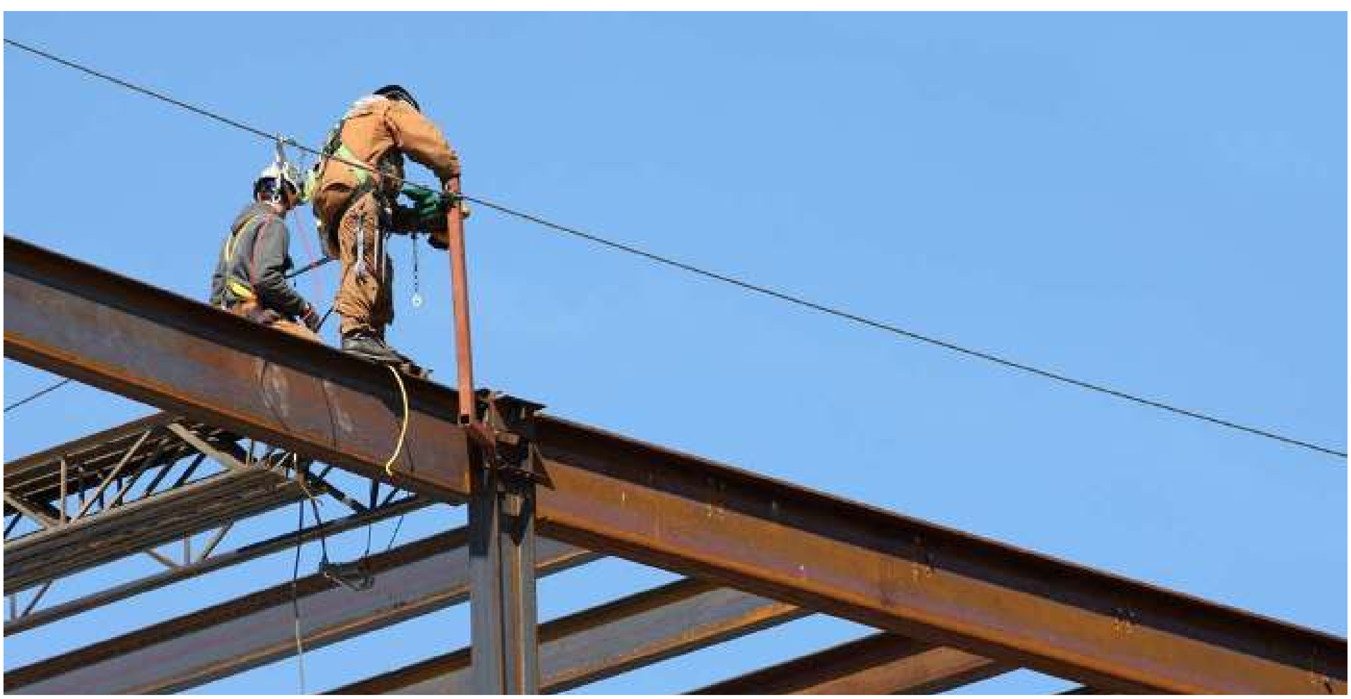
Figure 4.7 shows the financial value of projected labour hours by province. Even after normalizing for the size of the workforce across provinces and territories, Ontario and Quebec will experience the largest share of lost labour hours. This is because of the large proportion of workers in those provinces employed in manufacturing and other exposed industries and because Ontario and Quebec are projected to see the highest increase in number of days above the heat thresholds where productivity declines.

Figure 4.7

All provinces will see reductions in labour productivity

Projected annual labour productivity losses





Climate change will increase heat-related deaths in Canada

More frequent hot days in Canada will lead to more deaths, as Figure 4.8 shows. Under the high-emissions scenario, our modelling estimates an additional 400 heat-related deaths annually by mid-century. Mortalities will nearly double by the end of the century, reaching 790 annually. This is about 1.1 additional deaths per 100,000 people annually in the 2050s and 1.7 additional deaths per 100,000 annually by the 2080s.

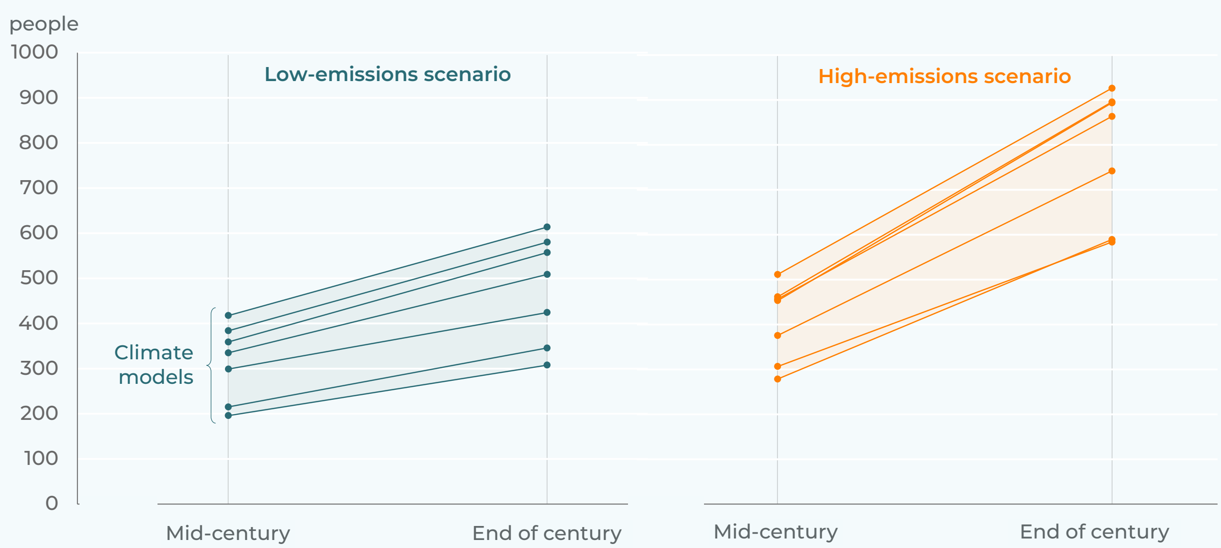
The costs of lost life and reduced quality of life from heat-related deaths are substantial. At mid-century, annual costs are similar under the low- and high-emissions scenarios—$3.0 billion and $3.9 billion respectively—but by the end of the century, the cost of failure to reduce emissions becomes much more apparent. In the high-emissions scenario, heat-related deaths are modelled to cost $8.5 billion annually by end of century, compared to $5.2 billion if global emissions are substantially reduced.

While these costs are clearly much higher than healthcare costs, it is important to put them into context. Avoiding these deaths won't put more money in bank accounts and government treasuries. But it does show how much people in Canada value reducing the risk that they or their loved ones will die prematurely from heat-related illness.

Figure 4.8

Hotter days means more deaths due to extreme heat

Projected annual heat-related death



Disadvantaged groups are at higher risk of heat-related illnesses and death

Some of the pre-existing diseases that affect heat risk are associated more strongly with disadvantaged groups. For example, in Canada, rates of diabetes among low-income adults are 1.8 times greater than among high-income adults (CIHI, 2016). Between 2010 and 2013, the prevalence of diabetes among Black people in Canada was 2.1 times the rate among white people (Abdillahi & Shaw, 2020). Key risk factors for diabetes, such as chronic stress and lifestyle, are strongly shaped by social factors like education and income.

Not only are people with lower incomes more likely to develop diabetes, they are also less likely to receive suitable care and are at higher risk of complications or premature death from it (CIHI, 2016). Rates of coronary heart disease are also higher among lower-income people, as well as among racialized people, regardless of income (Kreatsoulas & Anand, 2010; Veenstra & Patterson, 2016). A higher proportion of disadvantaged individuals are more sensitive to climate change heat hazards and are thus more likely to become ill or die from them.

Further, the productivity losses detailed above are concentrated in sectors where employment is lower-paid and more precarious. Recent immigrants and low-income individuals make up a disproportionate component of this labour force, in part because newcomers often encounter systemic and cultural barriers to finding employment at a level consistent with their training and work experience in their country of origin. For example, immigrants make up about 30 per cent of the workforce in manufacturing (Yssaad & Fields, 2018) and thus are more likely to be exposed to dangerous heat.

The benefits of heat adaptation

We also analyze two adaptation options that could reduce heat-related deaths (and their associated costs). One of these solutions reduces the exposure of people to health-related climate hazards by modifying buildings and urban landscapes to reduce air temperatures during hot weather. The other builds more general resilience by reducing homelessness, which reduces exposure to extreme heat of individuals without secure housing and also decreases their vulnerability to other health risks and challenges.

Green roofs and building shading can reduce exposure

Modifying buildings can reduce air temperatures for occupants and surrounding communities. Green roofs can reduce air temperature in urban areas while also serving to improve air quality, manage storm runoff, and sequester carbon. It is relatively inexpensive to install shades on homes and other buildings, and they have been shown to reduce internal daytime temperatures by two to three degrees Celsius (Vivid Economics, 2019)

Green roofs have a cooling effect that can reduce overall ambient temperatures in urban areas by about 0.04 degrees Celsius for each 10 per cent of roof space that is converted (Rosenzweig et al., 2003; Smart Prosperity, 2020). The benefits of green roofs therefore extend to all residents of an area where they are constructed, not just to building occupants (Kjellstrom et al., 2016; Vivid Economics, 2019).

In addition to estimated reductions in heat-related deaths and associated costs, we also modelled the benefits that green roofs and shading confer in energy savings from reduced heating and cooling. We also incorporated other economic benefits of green roofs including those linked to improved air quality, reduced storm runoff, and carbon sequestration. Our results show the following:

- If shading technologies were installed on 25 per cent of homes in Canada by the 2050s, there would be an average of 21 fewer deaths per year; if shading was installed on 50 per cent of homes by 2085, there would be an average of 90 fewer deaths per year. The social benefit of the avoided premature heat-related deaths by the 2080s would be approximately $540 million (using VSL), and the total energy savings are estimated at almost $1.4 billion. After taking into account the initial investment and operating and maintenance costs, the annual net benefit is over $1.3 billion.
- If 50 per cent of all residential, commercial, and institutional buildings had green roofs installed by the 2050s, an average of 46 deaths would be avoided annually; putting green roofs on 100 per cent of buildings by the 2080s would result in an average of 99 fewer deaths. The annualized investment and operating costs of this many green roofs would be substantial, at $17 billion by 2080. The total annual benefit would amount to $28 billion ($1.1 billion in social benefit from avoided deaths and $26.9 billion from energy savings and other savings listed above). The annual net benefit of implementing green roofs at this scale would be about $12 billion.
- Installing shading technologies on 25 per cent of Canada's manufacturing facilities by the 2050s, and 50 per cent by the 2080s, would save an average of 4 million and 15 million labour hours, respectively. The costs of installation and maintenance of shading technology at this scale are modest, at only $86 million annually by the 2080s, but would save workers in Canada $250 million annually in wages that would otherwise be lost. Labour productivity benefits to the Canadian economy would be even larger, estimated to boost GDP by over $430 million.

Increasing housing security can address root causes of vulnerability

Investing in reducing homelessness gives housing-insecure individuals safe housing during hot weather, among other benefits. For our analysis, we assumed that current rates of homelessness reported in the 2016 census for each province and territory are constant over the next 80 years (McDermott et al., 2019). We then test the reduced death toll if 50 per cent of people who are homeless are provided with housing and supportive services.

This analysis draws on evidence from Housing First public health programs that move people experiencing homelessness into independent housing and provide additional supports and services to make the transition permanent (Gaetz & Gulliver, 2013)—an approach that has been adopted by many provincial and territorial governments in Canada (ESDC, 2019). The Housing First approach is designed to address some of the root causes of homelessness, especially severe mental illness and barriers to health services. For our analysis, we looked at the costs and benefits of supplying both housing and supportive services to people that are housing insecure and that have severe mental illness.

Based on studies in multiple Canadian cities, we assumed incremental costs of $22,900 for housing and supportive services per person for the first year (Aubry et al., 2016; Latimer et al., 2020; Ly & Latimer, 2015). We also assumed a benefit of $16,500 per year in cost savings from reduced justice system costs and healthcare costs not associated with climate impacts. These assumptions provide a conservative estimate of savings, given that studies have found many individuals are able to support themselves after one year and no longer require housing subsidies and supportive services (Aubry et al., 2016; Latimer et al., 2020; Ly & Latimer, 2015).

We assumed that moving someone from being unsheltered to housed reduces their exposure to heat by four degrees Celsius. This assumption is based on the difference between street-level temperatures in dense urban environments and housing with air circulation but no air conditioning; urban heat islands can make street-level temperatures as much as five degrees Celsius higher than indoors (Rinner & Hussain, 2011; Wang et al., 2014). We also assume that people who are homeless with severe mental illness face a disproportionate rate of pre-existing health conditions and have an increased baseline risk of death, including 50 per cent greater likelihood of dying of heat exposure (Lim et al., 2008; Schmeltz & Gamble, 2017; Smetanin et al., 2015). Our findings are as follows:

- The annualized cost of the Housing First intervention would be $65 million in 2055 and $85 million in 2085.
- The annualized yearly co-benefit from reduced healthcare expenditures and justice system costs would be $54 million in 2055 and $70 million in 2085.
- The Housing First intervention would save an average of 1.6 lives per year by mid-century, for a benefit of $15 million. By the end of century, our modelling shows a reduction of 2.6 deaths per year and a benefit of $27 million.
- Under these assumptions, there would be roughly a break-even by mid-century and a net savings of $7.5 million per year by the 2080s.[4]

While the number of heat deaths that we model is the same order of magnitude as some actual observations (Condon & McDermid, 2014), we believe that the model underestimates the benefits of providing housing, given that we do not consider reduced exposure to cold and other health risks of being housing insecure.

Adaptation has multiple benefits

Our analysis shows that thoughtful and evidence-based adaptation investments can substantially reduce health impacts and deliver positive returns, often when just considering health costs alone. However, when examining the other co-benefits of adaptation—whether energy savings from shading, the variety of amenities from green roofs, or cost savings in social programs from curbing homelessness—the economic case for adaptation becomes even stronger.

These are not isolated cases. Many types of adaptations that have health benefits also deliver economic, social, and environmental benefits that can make Canada a fairer, safer, and more prosperous place to live, irrespective of a changing climate.

[4] If increasing housing for people only reduces temperature exposure by 2.5 degrees Celsius and if people who are homeless do not have any increased risk of death compared to the average population, then the benefit is reduced by about 20 per cent.

5

A WIDE-ANGLE VIEW OF CLIMATE-RELATED HEALTH COSTS

The costs and impacts of increasing heat, Lyme disease, and ground-level ozone we have considered above are significant but also incomplete. Many other health impacts and costs may affect Canada (Figure 5.1), which are challenging to model and estimate but are nonetheless material for decision makers and significant to people across Canada. To gain a big-picture perspective on climate health impacts, we draw on the growing body of evidence documenting recent impacts and costs in Canada associated with climate-related health hazards. Even though we can't predict exactly what the future may bring, understanding current impacts can help envision the implications for Canada as climate change progresses.

In this section we specifically focus on three major emerging climate change risks to health in Canada: a) mental health impacts; b) changes to cultures, livelihoods, security, and identities of Indigenous Peoples; and c) physical threats to healthcare infrastructure.

Mental illness

In the years ahead, climate change will increase the risk of mental illness for many people across Canada, affecting mental health, eroding well-being, and imposing substantial costs on individuals and society. Moreover, the individuals most affected are those already facing social and economic disadvantages (Hayes et al., 2018, 2019).

Mental illness and climate change are clearly linked

The acute fear and trauma associated with weather-related disasters such as floods, wildfires, and severe storms can lead to PTSD. In one study of evacuees from the 2016 Fort McMurray fire, 29 per cent met

Figure 5.1:

Known and unknown health-related risks in Canada: the climate costs iceberg

Climate change is bringing new threats onto Canada's horizon while amplifying existing hazards. A small number of the risks that Canadian households, communities, and businesses face are well understood. Many other risks are looming under the surface—researchers don't know yet how the risks will change over time or how they may interact with other social, environmental, and economic systems. Faced with this uncertainty, decision makers—and individuals—need to avoid the trap of inaction and instead adaptively manage these risks.

RISKS IN OUR PATH for which we can start to calculate the scale of impact and cost

- Impacts of heat and heat waves
- Effects of rising temperatures on urban air quality
- Spread of certain infectious diseases
- Impacts to Indigenous cultures and ways of life

CLIMATE IMPACTS WE SUSPECT WILL AFFECT CANADA but whose scope and scale we don't yet have the tools to understand

- Mental health impacts of weather-related disasters and environmental grief
- Effects of more frequent and widespread wildfire smoke on respiratory health
- Impacts to food- and water-borne illnesses
- Decreased exposure to extreme cold

RISKS THAT MAY HAVE MAJOR IMPACTS through complex interactions and processes and that are very challenging to predict

- Arrival and spread of new infectious diseases such as Zika virus
- Disruption affecting the operation and capacity of healthcare facilities, medical supply chains, and critical infrastructure during weather-related disasters
- Effects of domestic and international shortages on food and water security
- Injury and death from unprecedented weather-related disasters such as Northern heat waves or winter flash floods

criteria for PTSD, 26 per cent for depression, and 43 per cent for insomnia (Belleville et al., 2019). Another study showed a significant correlation between the 2013 Calgary flood and increased rates of PTSD symptoms in pregnant people (Hetherington et al., 2018). And it is not only those directly affected who are at risk; first responders and recovery personnel can be bombarded with traumatic stories and images during the response, which may also lead to mental illness (Osofsky et al., 2011). The link between floods and mental illnesses has been seen in other countries too, with consistent increases in PTSD and depression left behind by floodwaters (Neria & Galea, 2008; Rezayat et al., 2020).

Stress and uncertainty during post-disaster reconstruction and from the loss of landscapes and livelihoods can also increase the risk of depression and anxiety. For example, in the aftermath of the Fort McMurray wildfire, incidences of depression were 50 per cent higher for the general population and 14 per cent higher among children who lived through the disaster as compared to a nearby community not directly affected (Brown et al., 2019). After the 2013 Calgary flood, the number of patients seeking new prescriptions for anti-anxiety medications increased by approximately 65 per cent in affected neighbourhoods (Sahni et al., 2016). A recent study that looked at the impacts of disasters on substance use disorder showed upticks in fatal and non-fatal drug overdoses during and after the events (Public Health Ontario, 2020b).

More gradual climate changes can affect mental health as much as disasters. Changes to familiar landscapes and ecosystems are risk factors for “ecological grief”—intense feelings of sadness linked to these losses that can contribute to depression and anxiety and affect well-being (Cunsolo & Ellis, 2018; Tschakert et al., 2017).

Climate change will exacerbate the costs of mental illness

Mental illness in Canada is already a critical issue with major social and economic implications. About 12 per cent of adults in Canada self-report having a mood or anxiety disorder (Statistics Canada, 2013). One study estimates the costs of depression and anxiety to the Canadian economy at $34 billion and $17 billion per year, respectively, in lost productivity alone (Sutherland, 2016). In 2011, the annual direct costs of healthcare, social services, and income supports attributable to mental illness were conservatively estimated to be approximately $42 billion (Smetanin et al., 2015). Substance-use disorder—among the deadliest mental illnesses—is estimated to cost $35 billion per year due to healthcare costs, criminal justice costs, and productivity losses (Stockwell & Young, 2018).

Not accounting for climate change, the direct costs of mental illness in Canada are expected to grow to some $291 billion per year by 2041 (a 590 per cent increase), with cumulative costs over that 30-year period reaching more than $2.3 trillion. Even if climate change only moderately increases rates of mental illness, this could be among the costliest climate-related health impacts for Canada. And mental health services are already limited and underfunded, particularly for low-income people and those without supplementary health insurance. Climate change will therefore increase demand on a system that is already stretched thin (Kowalewski et al., 2011; Nader et al., 2017; Patel, 2019; Thomson et al., 2015).

Mental illnesses further affect those facing social disadvantages

Just like any other disease, many factors influence mental illness, including life experience, environment, and socioeconomic conditions. Mental health is strongly connected to housing, education, and income status, which influence social connectedness, control, access to medical care, and personal sense of dignity (Allan & Smylie, 2015; CMHA, 2008). At the same time, mental illness may contribute to poverty through exclusion from employment and education, particularly for individuals with severe mental illness (Poremski et al., 2015).

Inuit, First Nations, and Métis Peoples often have a higher baseline incidence of mental illness rooted in colonialism, disempowerment, and a lack of appropriate and accessible healthcare. Losses to landscapes, livelihood, and culture caused by climate change will likely worsen mental health challenges for many Indigenous Peoples (Do et al., 2013; Nelson & Wilson, 2017; Pollock et al., 2018).

Gender will also affect susceptibility to the mental health impacts of climate change. Evidence of gendered effects of weather-related disasters on mental health suggests that women disproportionately bear the burden because of norms related to gender roles, caregiving responsibilities, and underpaid and undervalued work (Williams et al., 2018).

Additionally, LGBTQ2S+[5] populations experience a disproportionate incidence of mental illness due largely to discrimination and challenges in accessing services. Lesbian, gay, and bisexual youth are seven times more likely to attempt suicide compared to their straight peers (Suicide Prevention Resource Centre, 2008). Disaster response and recovery policies designed for straight, nuclear families have also been shown to underserve LGBTQ2S+ populations (Dominey-Howes et al., 2014; Sellers, 2018).

[5] LGBTQ2S+ is an acronym for lesbian, gay, bisexual, transgender, queer/questioning, Two-Spirit, and non-normative gender identity.

Family and interpersonal violence

Weather-related disasters and the resulting instability can compound existing risk factors for family and interpersonal violence (Capaldi et al., 2012). While climate change is not solely responsible for violence, weather-related disasters cause trauma and instability that can compound existing risk factors. Disasters can disrupt social support networks and strain finances, making it more challenging for people to leave dangerous living situations (Gearhart et al., 2018). Disasters have also been shown to increase the need for resources like shelters or helplines; these services are often already limited, and disasters can overwhelm their capacity (Bell & Folkerth, 2016; Enarson, 1999). Further, the budgets of these services are often cut during economic downturns and are highly dependent on donations, meaning that they may be underfunded exactly when they are needed most. In the U.S., domestic violence reports and helpline calls increased in the aftermath of disasters like Hurricane Katrina (Parkinson, 2019). In Alberta, social agencies reported an increase in domestic violence after the 2013 floods (Graveland, 2014; Sahni et al., 2016).

While a person of any gender can be the survivor of intimate partner violence, the majority are women. In 2016, women made up 79 per cent of survivors of self-reported intimate partner violence in Canada, at an estimated rate of 483 per 100,000 (Statistics Canada, 2016). Indigenous women, in particular, are at risk of violence, experiencing rates three times that of non-Indigenous women (MMIWG, 2019).

While climate-related stresses can exacerbate the risk of violence, other factors such as unemployment, income, and personal history are the most important underlying risk factors. Therefore, the most effective adaptations will need to address these root causes.

Impacts on culture, livelihoods, and identity

The effects of climate change on food and water security, livelihoods, culture and identity, and safety could have substantial impacts on physical, mental, and spiritual health for people across Canada. This is especially true for Indigenous Peoples, whose livelihoods and cultures are often intimately connected to local landscapes and ecosystems (Bourque & Cunsolo Willox, 2014; Middleton et al., 2020; Tester, 2010; TRC, 2015).

Climate change amplifies threats to Indigenous culture and identity

Indigenous Peoples across Canada are strong and resilient, but many communities are highly exposed to climate change impacts that threaten health, safety, culture, and ways of life. Thawing permafrost and changing ice and snow conditions make Northern homes uninhabitable, threaten drinking water supplies, and cut off community access to emergency medical care and services (Native Women's Association of Canada, 2020; Streicker, 2016). Ecosystem and landscape changes lead to the loss of traditional food sources and harvesting practices, livelihoods, medicinal plants used in traditional healing, and important spiritual and ceremonial sites (Wyllie de Echeverria & Thornton, 2019).

In many cases, historic and ongoing colonial policies and practices have also diminished Indigenous Peoples' ability to adapt to climate change. Economic poverty, unsafe housing conditions, water insecurity, and infrastructure disparities are a lived reality in many communities. These crises often demand immediate response from local governments, pulling already limited resources away from planning for future risks. Policies that criminalized Indigenous culture, forced displacement, and caused economic marginalization—all associated with colonialism—continue to also impact the baseline health and well-being of many Indigenous communities (Ford et al., 2015; Lawson, 2019). While Indigenous knowledge continues to support the livelihoods and safety of Indigenous Peoples, historic and ongoing colonialism continues to impact socioeconomic conditions, impeding access to the land that is integral to Indigenous ways of knowing and being. This has subsequently affected the capacities of many Indigenous Peoples to adapt to new or emerging hazards (Clark et al., 2016b; Ford et al., 2013, 2017; Ready & Collings, 2020; Ribot, 2014).

Climate-related food insecurity threatens health and cultural identity

Food security is not only an important element of physical health for Indigenous Peoples but also of cultural identity and well-being. Traditional food is integrally connected to identity, culture, community, knowledge, and relationships with the land (Durkalec et al., 2015; Neufeld et al., 2017). Indigenous Peoples in Canada experience food insecurity at a rate of three to five times the national average (Chan et al., 2019; Tarasuk & Mitchell, 2020). Food insecurity is tied to colonialism, dispossession of land and traditional food harvesting areas, environmental degradation, and economic disadvantage, all of which can make it difficult to access food through either traditional or market systems (Power, 2008; Richmond et al., 2021; Richmond & Ross, 2009).

Climate change further threatens traditional food sources with shifting seasons, changing habitats, and emerging diseases that threaten the abundance and quantity of native plants and animals. Warming temperatures thaw the snow, ice, and permafrost, impacting hunting and travel on the land. Climate change is making it more difficult for remote Indigenous communities to access store-bought foods, as snow and ice roads are becoming less reliable and supplies need to be transported by air (Human Rights Watch, 2020).

Inuit cultural impacts

Inuit Qaujimajatuqangit (IQ), or Inuit traditional knowledge, has successfully guided Inuit adaptation to changing environmental conditions for millennia (Karetak et al., 2017). While the current pace of environmental change across the Inuit Nunangat was never experienced by the ancestors, the cultural tenets of *Qanuqtuurniq* (innovation and resourcefulness), *Piliriqatigiinniq* (collaboration with a common goal), and *Avatittinnik Kamatsiarniq* (care and respect for the land and environment), among others, have provided and continue to provide a foundation for community resilience across Inuit Nunangat (Aporta et al., 2005; Brody, 1987; Healey et al., 2011; Tester & Irniq, 2008). While communities across the North are strong and resilient, the impacts of food and housing insecurity and economic barriers to subsistence activities can limit their capacity to adapt (Ford et al., 2014, 2015).

For many Inuit, engaging in activities on the land is foundational to identity and culture. However, participation in travel, harvesting, and other traditional activities has been challenged by changes to the ways Indigenous knowledge is used and passed down, changes in technology, and colonialization (Clark et al., 2016b; Huntington et al., 2017; Wenzel, 2009, 2013). On top of these changes, climate change is now affecting the seasonality and range of wildlife and plants and the predictability of ice and weather, altering the relevance of centuries of knowledge, making travel more dangerous, and making harvesting of safe and culturally appropriate foods difficult, if not impossible (Clark et al., 2016a; Durkalec et al., 2015; Ford et al., 2019a; 2019b). These losses to traditional cultural practices and identity represent intangible loss and damage: they are incalculable in economic terms but are nonetheless profound (Tschakert et al., 2017).

Dylan Clark: Pangnirtung, Nunavut

Impacts on land and wildlife affect cultures, economic well-being, and identity

Non-Indigenous peoples across Canada have also described losses of culture and identity associated with climate change. While these impacts are distinct from the losses that Indigenous Peoples are facing and have faced, they are nonetheless significant to the health and well-being of many people across Canada (Cunsolo & Ellis, 2018; Ellis & Albrecht, 2017; Tschakert et al., 2017).

For example, hunters, anglers, and trappers across Canada that depend on annual migrations and healthy ecosystems to sustain their annual harvests are seeing changes in their surroundings. Climate change impacts to forests, including the proliferation of pests like the mountain pine beetle, increases in the frequency and size of wildfires, and reduced growth rates due to drought are devastating forest-dependent communities (NRCan, 2020). Similarly, communities reliant on fishing are also being affected by changes to fish habitat, health, and abundance—some of which are linked to climate change (Brander, 2010; CCA, 2019; Le Bris et al., 2018).

The declining health of landscapes and ecosystems across Canada not only has economic implications but also affects mental and physical health (McDowell, 2020). As climate change accelerates shifts already underway as a result of development and resource extraction, it may become more difficult for communities and individuals to maintain a sense of place that sustains their physical and mental well-being (Hess et al., 2008; Tschakert et al., 2017).

Physical risks to health infrastructure

Health systems across Canada are staring down two storms in a changing climate: increasing demand from climate-related impacts on health and physical risks to health infrastructure and supply chains. Until this point in the report, we have focussed on the former—how weather-related disasters and other climate change health impacts could increase illness and strain health systems across Canada.

Climate change also poses risks for electricity, drinking water, emergency response facilities, road and air medical evacuation services, and supply chains for equipment and medicine. When this infrastructure is damaged by a climate hazard, the effects can ripple out to health systems. Not only could weather-related disasters like wildfires and floods incapacitate infrastructure that is critical to health systems in Canada at all times but it could knock out this critical infrastructure exactly when it is most needed (Ebi et al., 2018; Ghazali et al., 2018; Paterson et al., 2014).

Ensuring people can access medical care in an emergency requires more proactive preparation across health systems. Healthcare infrastructure will benefit from general disaster preparedness and planning by local or regional governments, such as policies to prevent new facilities from being built in high-risk zones (Burton et al., 2016; Feltmate & Moudrak, 2016). There are also specific actions that individual health facilities and networks can undertake, such as developing emergency disaster plans that account for ways severe weather can directly and indirectly affect their buildings and supply chains (Paterson et al., 2014). Despite how important resilient health infrastructure is, less than 20 per cent of health authorities have assessed the vulnerability of their healthcare facilities to climate change risks (Berry, 2019).

Flood risk to healthcare facilities

As temperatures rise, floods are projected to become more frequent and severe in many communities across Canada. Floods can directly damage healthcare facilities and can also affect health systems by affecting medical supply chains, causing electrical and water service outages, and increasing patient loads. During past floods in other countries, disruptions have created a deadly cascade, with health facilities facing both diminished capacity and increased demand (Achour & Price, 2010). In response to the increasing risks, healthcare facilities need to adapt and plan accordingly.

To illustrate the scale of this risk, we analyzed the percentage of healthcare facilities in each province and territory that are currently at risk of flooding, based on commercially available flood risk mapping for Canada (Table 5.1). Healthcare facilities analyzed include hospitals, long-term care centres, and community health centres. There are a surprising number of facilities at risk of flooding in most provinces and territories. Manitoba and Yukon have the largest percentage at risk of flooding, likely because their largest population centres are beside major rivers with much development in the floodplain. Yukon's high percentage of facilities in the floodplain and small total number of facilities illustrate how weather-related disasters driven by climate change could disrupt and damage important health infrastructure when it is most needed. Many Northern residents already face substantial barriers to accessing healthcare, as health facilities are sparse. If a facility is damaged or closed, residents could be forced to travel even farther to access care.

Table 5.1

Percentage of healthcare centres at risk of flooding

Province/Territory	Number of facilities	20-year flood	50-year flood	75-year flood	100-year flood
YT	24	21%	21%	21%	21%
MB	373	9%	15%	17%	18%
NL	144	8%	10%	11%	12%
NWT	30	1%	10%	10%	10%
BC	619	6%	8%	9%	9%
AB	1,072	4%	7%	8%	8%
PEI	55	7%	7%	7%	7%
QC	804	5%	6%	7%	7%
SK	389	3%	4%	6%	6%
NB	213	2%	5%	5%	5%
NS	203	4%	5%	5%	5%
ON	1,440	4%	5%	5%	5%
NU	27	4%	4%	4%	4%
Total	**5,393**	**5%**	**7%**	**7%**	**8%**

Note: Healthcare facility data from DMTI Spatial, flood data from JBA Analytics

Our findings align with other research that concluded a similar number of healthcare facilities are at risk of flooding and that also found a similar proportion of police and fire stations were at risk (Scott et al., 2020).

6

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions emerge from our analysis:

Climate change is a major threat to health and well-being across Canada.

The health impacts of extreme heat, urban smog, wildfires, floods, and infectious disease are already being felt across the country and will only continue to get worse. Our analysis shows that heat and smog alone could lead to hundreds of thousands of early deaths and compromise the health and productivity of hundreds of thousands of people by the end of the century. Each year, these impacts could cost Canada's healthcare system billions of dollars, reduce economic activity to the tune of tens of billions, and reflect hundreds of billions in social costs of lost quality of life and premature death. And these costs are just the tip of the iceberg, representing only a small slice of potential health effects related to climate change.

The full scope and scale of potential climate change health impacts in Canada remain uncertain.

Most health adaptation research and policy in Canada is guided by the federal government and has so far focussed on a relatively narrow range of health impacts and adaptation solutions. Emerging threats (such as mental health impacts) have not been widely studied yet may hugely exceed the costs of relatively narrow areas that have received significant focus (such as Lyme disease). Other critical risks that threaten the ability to safeguard health in a changing climate, such as the vulnerability of healthcare infrastructure to extreme weather, are also not well understood. Health impacts that are specific to locations or regions have not been given as much attention from the largely top-down national research agenda. And most of the limited health adaptation activity in Canada focusses on addressing symptoms, not delivering systemic solutions.

Disadvantaged individuals and groups will bear the brunt of climate change health impacts.

Racism, colonialism, poverty, and homelessness are social determinants of health that are just as significant to health outcomes as age and genetics, if not more so. These structural factors put up roadblocks to health and well-being at the best of times. That unequal footing means the health impacts of climate change are not going to be felt equally. However, the economic costs of these impacts—if not prevented or reduced through adaptation—will be borne by the entire country.

We have an opportunity to reduce these impacts—both known and unknown—before they occur.

Reducing greenhouse gas emissions will lessen the health impacts induced by climate change. However, even with significant emissions reductions, Canada will still face growing health impacts and financial and human costs. Protecting health and well-being across Canada in the face of climate change will require adaptation to prepare for current and future impacts and build resilience. This means that, while health adaptation will require new activities and policies, in some cases it also requires that governments cease activities or policies that are increasing vulnerability.

Canada has a substantial deficit in health-related adaptation.

Although we did not conduct a systematic health adaptation gap analysis, the available evidence suggests that progress on health adaptation in Canada is not keeping pace with the growing threat. Our research uncovered a number of possible reasons: the scale of health impacts is not yet understood; health adaptation is underfunded and underprioritized; coordination across and within governments to address root causes of health risks is lacking; and slow overall progress on adaptation in Canada means there has been little headway on reducing the risk of climate change health hazards like extreme weather and flooding. Continued inequity in social determinants of health is further limiting progress in building the health resilience of disadvantaged communities.

Health adaptation faces a big governance challenge.

Potential policy solutions for health adaptation and resilience implicate multiple departments across all orders of government—social services, housing, infrastructure, education, finance, and more. Solutions that address root causes obviously have complex implications and trade-offs that go well beyond climate change. At the same time, current policies are failing to generate health adaptation and resilience benefits, precisely because the complexities of climate risks and impacts are being insufficiently considered in decision-making. This governance challenge is critical: without addressing it, the default focus of health adaptation in Canada will be on decentralized management of symptoms—an approach that will ultimately be ineffective.

Greenhouse gas emissions need to be addressed.

As our analysis shows, the health impacts of climate change are much more severe and costly in a future of high global emissions. Ultimately, one of the most effective ways to reduce health impacts will be to ensure that greenhouse gas emissions are minimized. Further, domestic action in Canada on reducing greenhouse gas emissions will create direct and immediate benefits by reducing some of the health impacts we have analyzed. For example, a transition to electric vehicles and non-combustive heating will reduce the prevalence of air pollutants that lead to the formation of ground-level ozone, counteracting the effects of rising temperatures that will drive additional ozone formation. Other actions to reduce emissions such as insulating buildings and transitioning gas and oil heating to heat pumps—which can also act as air conditioners—will help protect residents from exposure to dangerous heat.

Recommendations for policy makers

How then can Canadian governments respond to these challenges? The following recommendations outline key policy choices that can accelerate climate change adaptation for health in Canada:

1 All orders of government should implement health adaptation policies to address both symptoms and root causes.

Policies that tackle the *symptoms* of health impacts can play a clear role in reducing risks. For example, governments can enhance warnings about heat and poor air quality, ensure emergency response systems are primed for more extreme weather, fund data-tracking and treatment of new or changing infectious diseases such as Lyme disease, and fund or require training for healthcare professionals to deal with these new threats.

Despite their benefits, however, health adaptation efforts that are limited to symptoms and proximate effects will ultimately be unable to keep up with growing and unpredictable climate change impacts. That means that governments should also implement policies that address the *root causes* of vulnerability and exposure.

Some root causes are social. Improving access for all people to public health and healthcare resources, quality education, safe and affordable housing, and social and cultural supports can tackle some of the roots of vulnerability to climate change.

Other root causes are physical. Building codes can be updated to improve resilience to flooding and extreme heat. Changes to land use planning policies can reduce urban heat island effects. Policies to promote the shift toward electric and zero-emissions vehicles can reduce ground-level ozone that combines with warmer temperatures to worsen air quality.

2 Canada's emerging national adaptation strategy should map all key adaptation policy levers across government departments and orders of government against top climate health impact areas.

Given the governance complexity around health adaptation, identifying specific opportunities to address symptoms and root causes is a challenge. The current ad hoc, compartmentalized approach to health adaptation in Canada will not address the root causes of inequitable vulnerability and exposure to climate change health risks.

As a result, when developing the forthcoming national adaptation strategy, the Government of Canada should explicitly recognize the decentralized nature of health adaptation and resilience building. It should work with provincial, territorial, Indigenous, and local government partners to identify bodies that make policy decisions to improve health resilience. Mapping these accountabilities can more concretely articulate the governance problem that we have framed and help start the discussion about how policy decisions that advance health adaptation will be coordinated within and across orders of government.

3 Central agencies in federal, provincial, and territorial governments should explicitly incorporate health resilience into climate lenses to inform cost-benefit analyses and policy decisions.

All government departments should be directed to identify their role in climate change health adaptation and resilience and to take responsibility for those roles in departmental goals, projects and decisions. Departments should consider not just overall quantitative costs and benefits of alternative actions with respect to climate change health impacts but also the distribution of costs and benefits—recognizing that improving the circumstances of disadvantaged groups builds overall resilience.

4 Governments should invest in research on emerging, unknown, and local climate change health impacts.

Successful health adaptation policy must address health risks broadly, not only the narrower set of impacts of climate change that are most studied. Broad risks include mental health impacts, the effects of changes in wildfire regimes on air quality and respiratory health, the vulnerability of health systems themselves to climate change and extreme weather, and the direct and indirect effects of ecosystem change on health and well-being. Provincial, territorial, Indigenous, and local governments should also invest in better understanding the regional and local health implications of climate change, including the exposure and sensitivity of disadvantaged groups.

GLOSSARY

The definitions in this section reflect how key terms below are used in this paper and in the discipline of climate change adaptation research. Many terms here also have alternate meanings or application outside of climate-related contexts.

Adaptation	The ways in which human and natural systems adjust to reduce the harmful effects of climate-related changes and capitalize on the benefits.
Adaptive capacity	The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce negative impacts, reduce harm, or exploit beneficial opportunities resulting from climate change.
Baseline	The baseline (or reference) is the state against which change is measured. A "current baseline" represents observable, present-day conditions. A "future baseline" is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Climate	The average weather in a place over a long period of time, typically decades or longer.
Climate change	Changes in the usual climate of the Earth, predominantly caused by the burning of fossil fuels, which add heat-trapping gases to Earth's atmosphere. It manifests as overall global warming but also in sea level rise, melting of previously permanent snow and ice, and more extreme weather.
Climate extreme (extreme weather or climate event)	The occurrence of a weather or climate variable (such as temperature) that falls above or below the upper or lower limits of observed values for that variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as "climate extremes."
Climate model	A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes and that accounts for all or some of its known properties. Climate models are applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal, and interannual climate predictions.
Climate projections	Estimates of the response of the Earth's climate to a range of plausible pathways that capture the relationships between human choices, greenhouse gas concentrations, and temperature change. Climate projections are distinguished from climate predictions to emphasize that there is major uncertainty associated with this range of plausible futures and that none can generally be predicted to be more likely than others.
Disadvantaged	Individuals or groups that experience barriers in accessing resources and are underrepresented in societal institutions.

Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with conditions of social vulnerability, leading to widespread negative human, material, economic, or environmental effects that require an immediate emergency response to satisfy critical needs and may require external support for recovery. Disaster risk is the likelihood that a disaster will occur within a specified period.
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected by climate change.
Hazard	The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage or loss to property, infrastructure, livelihoods, service provision, or environmental resources.
Heat wave	A period of temperatures higher than what is normally expected (based on historic climate averages). Heat waves may span several days to several weeks.
Impacts	Effects on natural and human systems. In this report, the term "impacts" is used to refer to the effects on natural and human systems of physical events, disasters, and/or climate change.
Incidence	A measure of the frequency with which a symptom or disease, such as heart attack, happens in a given population over time.
Mental Illness	A wide range of disorders that affect mood, thinking, and behaviour. Examples include depression, anxiety disorders, schizophrenia, and substance use disorders.
Morbidity	Illness. One person can have multiple illnesses ("co-morbidities").
Mortality	Death. Rates are typically expressed as the number of deaths per year per 100,000 people.
Racialized	The process by which people are identified by racial characteristics. Since white people have historically held economic and political power in Canada, racialized is generally used in a Canadian context to refer to visible minorities.
Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as probability of the occurrence of hazardous events or trends, multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of impacts related to climate change.
Sensitivity or susceptibility	The degree to which an individual, asset, household, community, business, or ecosystem is affected, either adversely or beneficially, by climate variability or change.
Social determinants of health	The broad range of personal, social, economic, and political factors that determine a person's access to healthcare and resources and influence their health.
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, negative effects of climate change, including climate variability and extremes.

REFERENCES

Abdillahi, I., & A. Shaw. 2020. *Social determinants and inequities in health for Black Canadians: A Snapshot*. Social Determinants of Health Division, Public Health Agency of Canada.

Achour, N., A.D.F Price. 2010. "Resilience strategies of healthcare facilities: present and future." *International Journal of Disaster Resilience in the Built Environment* 1(3): 264-276.

Adger, W. N. 2006. "Vulnerability." *Global Environmental Change* 16(3): 268–281.

Adger, W. N., J. M. Pulhin, J. Barnett, G. D. Dabelko, G. K. Hovelsrud, M. Levy, S. Ú. Oswald, C. H. Vogel, U. Oswald Spring & C. H. Vogel. 2014. "Human security." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*, eds. C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White. Cambridge, U.K.: Cambridge University Press.

Allan, B., & J. Smylie. 2015. *First Peoples, Second Class Treatment: the Role of Racism in the Health and Well-being of Indigenous Peoples in Canada, Discussion Paper*. Wellesley Institute.

Angus Reid Institute. 2015. *Prescription Drug Access and Affordability an Issue for Nearly a Quarter of all Canadian households*. Angus Reid Institute. Vancouver, Canada.

(APA) American Psychiatric Association. 2013. *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)*. American Psychiatric Publications.

Aporta, C., E. Higgs, D. Hakken, L. Palmer, M. Palmer, R. Rundstrom, B. Pfaffenberger, G. Wenzel, & T. Widlok. 2005. "Satellite culture: global positioning systems, Inuit wayfinding, and the need for a new account of technology." *Current Anthropology* 46(5): 729–753.

Åström, D. O., K. L. Ebi, A. M. Vicedo-Cabrera, & A. Gasparrini. 2018. "Investigating changes in mortality attributable to heat and cold in Stockholm, Sweden." *International Journal of Biometeorology* 62(9): 1777–1780.

Atkinson, R. W., B. K. Butland, C. Dimitroulopoulou, M. R. Heal, J. R. Stedman, N. Carslaw, D. Jarvis, C. Heaviside, S. Vardoulakis, & H. Walton. 2016. "Long-term exposure to ambient ozone and mortality: a quantitative systematic review and meta-analysis of evidence from cohort studies." *BMJ Open* 6(2), e009493.

Aubry, T., P. Goering, S. Veldhuizen, C. E. Adair, J. Bourque, J. Distasio, E. Latimer, V. Stergiopoulos, J. Somers, D. L. Streiner, & S. Tsemberis. 2016. "A multiple-city RCT of housing first with assertive community treatment for homeless Canadians with serious mental illness." *Psychiatric Services* 67(3): 275–281. https://doi.org/10.1176/appi.ps.201400587

Austin, S. E., R. Biesbroek, L. Berrang-Ford, J. D. Ford, S. Parker, & Fleury, M. D. 2016. "Public health adaptation to climate change in OECD countries." *International Journal of Environmental Research and Public Health* 13(9): 889.

Austin, S. E., J. D. Ford, L. Berrang-Ford, M. Araos, S. Parker, & M. D. Fleury. 2015. "Public health adaptation to climate change in Canadian jurisdictions." *International Journal of Environmental Research and Public Health* 12(1): 623–651. https://doi.org/10.3390/ijerph120100623

Austin, S. E., J. D. Ford, L. Berrang-Ford, R. Biesbroek, & N. A. Ross. 2019. "Enabling local public health adaptation to climate change." *Social Science & Medicine* 220 (January): 236–244.

Awuor, L., R. Meldrum, & E. N. Liberda. 2020. "Institutional engagement practices as barriers to public health capacity in climate change policy discourse: Lessons from the Canadian province of Ontario." *International Journal of Environmental Research and Public Health* 17(17): 1–35. https://doi.org/10.3390/ijerph17176338

Barnett, A. G., S. Hajat, A. Gasparrini, & J. Rocklöv. 2012. "Cold and heat waves in the United States." *Environmental Research* 112 (January): 218–224.

BC Ministry of Environment and Climate Change Strategy. 2019. *Preliminary Strategic Climate Risk Assessment for British Columbia*. Government of British Columbia.

Beck, A. F., B. Huang, J. M. Simmons, T. Moncrief, H. S. Sauers, C. Chen, P. H. Ryan, N. C. Newman, & R. S. Kahn. 2014. "Role of financial and social hardships in asthma racial disparities." *Pediatrics* 133(3): 431–439. https://doi.org/10.1542/peds.2013-2437

Bélanger, D., P. Gosselin, P. Valois, & B. Abdous. 2014. “Perceived adverse health effects of heat and their determinants in deprived neighbourhoods: a cross-sectional survey of nine cities in Canada.” *International Journal of Environmental Research and Public Health* 11(11): 11028–11053.

Bell, S. A., & L. A. Folkerth. 2016. “Women’s Mental Health and Intimate Partner Violence Following Natural Disaster: A Scoping Review.” *Prehospital and Disaster Medicine* 31(6): 648–657. https://doi.org/10.1017/S1049023X16000911

Belleville, G., M. C. Ouellet, & C. M. Morin. 2019. “Post-traumatic stress among evacuees from the 2016 Fort McMurray wildfires: Exploration of psychological and sleep symptoms three months after the evacuation.” *International Journal of Environmental Research and Public Health* 16(9). https://doi.org/10.3390/ijerph16091604

Berry, P. 2019. “Health Risks and Vulnerabilities Due to Climate Change in Canada: New Evidence and HealthADAPT.” NCCEH Seminar by Climate Change and Innovation Bureau, Safe Environments Directorate, Health Canada. May 2019. https://www.ncceh.ca/sites/default/files/NCCEH%20EH%20Seminar%20May%2029%202019_Risks%20and%20Vulnerabilities%20due%20to%20Climate%20Change%20in%20Canada.pdf

Berry, P., K. Clarke, M. D. Fleury, & S. Parker. 2014. *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Natural Resources Canada. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Chapter7-Human-Health_Eng.pdf

Beverly, J. L., & P. Bothwell. 2011. “Wildfire evacuations in Canada 1980–2007.” *Natural Hazards* 59(1): 571–596. https://doi.org/10.1007/s11069-011-9777-9

Bouchard, C., A. Dibernardo, J. Koffi, H. Wood, P. Leighton, & L. Lindsay. 2019. “Increased risk of tick-borne diseases with climate and environmental changes.” *Canada Communicable Disease Report* 45(4): 83–89. https://doi.org/10.14745/ccdr.v45i04a02

Bourque, F., & A. Cunsolo Willox. 2014. “Climate change: The next challenge for public mental health?” *International Review of Psychiatry* 26(4): 415–422. https://doi.org/10.3109/09540261.2014.925851

Boyd, R., J. Eyzaguirre, F. Poulsen, M. Siegle, A. Thompson, S. Yamamoto, A. Osornio-Vargas, & A. Urcelay. 2020. *Costing Climate Change Impacts on Human Health Across Canada*. Canadian Institute for Climate Choices.

Brander, K. 2010. “Impacts of climate change on fisheries.” *Journal of Marine Systems* 79(3–4): 389–402. https://doi.org/10.1016/j.jmarsys.2008.12.015

Bresnahan, A., M. Brindamour, C. Charles, & R. Meili. 2017. *Upstream Medicine: Doctors for a Healthy Society*. Vancouver, B.C.: UBC Press.

Brody, H. 1987. *Living Arctic: Hunters of the Canadian North*. London, U.K.: Faber and Faber Limited.

Brown, M. R. G., V. Agyapong, A. J. Greenshaw, I. Cribben, P. Brett-MacLean, J. Drolet, C. McDonald-Harker, J. Omeje, M. Mankowsi, & S. Noble. 2019. “After the Fort McMurray wildfire there are significant increases in mental health symptoms in grade 7–12 students compared to controls.” *BMC Psychiatry* 19(1): 18.

Burton, H., F. Rabito, L. Danielson, & T. K. Takaro. 2016. “Health effects of flooding in Canada: A 2015 review and description of gaps in research.” *Canadian Water Resources Journal* 41(1–2): 238–249. https://doi.org/10.1080/07011784.2015.1128854

Bush, E., & D. S. Lemmen, eds. 2019. *Canada’s Changing Climate Report*. Government of Canada. Ottawa, ON. https://changingclimate.ca/CCCR2019

Cakmak, S., C. Hebbern, J. Vanos, D. L. Crouse, & R. Burnett. 2016. “Ozone exposure and cardiovascular-related mortality in the Canadian Census Health and Environment Cohort (CANCHEC) by spatial synoptic classification zone.” *Environmental Pollution* 214: 589–599.

Capaldi, D. M., N. B. Knoble, J. W. Shortt, & H. K. Kim. 2012. “A systematic review of risk factors for intimate partner violence.” *Partner Abuse* 3(2): 231–280.

(CCA) Council of Canadian Academies. 2019. *Canada’s Top Climate Change Risks: the Expert Panel on Climate Change Risks and Adaptation Potential*. https://cca-reports.ca/wp-content/uploads/2019/07/Report-Canada-top-climate-change-risks.pdf

Chan, L., M. Batal, T. Sadik, C. Tikhonov, H. Schwartz, K. Fediuk, A. Ing, L. Marushka, K. Lindhorst, L. Barwin, P. Berti, K. Singh, & O. Receveur. 2019. *FNFNES Final Report for Eight Assembly of First Nations Regions: Draft Comprehensive Technical Report*. Assembly of First Nations.

Charron, I. 2016. *A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions, 2016 Edition*. Ouranos. https://www.ouranos.ca/publication-scientifique/Guidebook-2016.pdf

Chestnut, L. G., & P. De Civita. 2009. *Economic Valuation of Mortality Risk Reduction*. Government of Canada, Policy Research Initiative.

Christidis, T., A. C. Erickson, A. J. Pappin, D. L. Crouse, L. L. Pinault, S. A. Weichenthal, J. R. Brook, A. van Donkelaar, P. Hystad, R. V. Martin, M. Tjepkema, R. T. Burnett, M. Brauer. 2019. "Low concentrations of fine particle air pollution and mortality in the Canadian Community Health Survey cohort." *Environmental Health* 18(84).

(CIHI) Canadian Institute for Health Information. 2016. *Trends in Income-Related Health Inequalities in Canada: Technical Report*.

(CIHI) Canadian Institute for Health Information. 2018. *Asthma Hospitalizations Among Children and Youth in Canada: Trends and Inequalities Chartbook*.

(CIHI) Canadian Institute for Health Information. 2019. *National Health Expenditure Trends, 1975 to 2019*. https://www.cihi.ca/en/national-health-expenditure-trends-1975-to-2019

(CIHI) Canadian Institute for Health Information. 2021. "OECD Interactive Tool: International Comparisons." https://www.cihi.ca/en/oecd-interactive-tool-international-comparisons

Clark, D. G., & J. D. Ford. 2017. "Emergency response in a rapidly changing Arctic." *CMAJ* 189(4): e135–e136). https://doi.org/10.1503/cmaj.161085

Clark, D. G., J. D. Ford, L. Berrang-Ford, T. Pearce, S. Kowal, & W. A. Gough. 2016a. "The role of environmental factors in search and rescue incidents in Nunavut, Canada." *Public Health* 137: 44–49. https://doi.org/10.1016/j.puhe.2016.06.003

Clark, D. G., J. D. Ford, T. Pearce, & L. Berrang-Ford. 2016b. "Vulnerability to unintentional injuries associated with land-use activities and search and rescue in Nunavut, Canada." *Social Science and Medicine* 169: 18–26. https://doi.org/10.1016/j.socscimed.2016.09.026

Clow, K. M., P. A. Leighton, N. H. Ogden, L. R. Lindsay, P. Michel, D. L. Pearl, & C. M. Jardine. 2017. "Northward range expansion of Ixodes scapularis evident over a short timescale in Ontario, Canada." *PLoS One* 12(12), e0189393.

Clow, K. M., N. H. Ogden, L. R. Lindsay, P. Michel, D. L. Pearl, & C. M. Jardine. 2016. "Distribution of ticks and the risk of Lyme disease and other tick-borne pathogens of public health significance in Ontario, Canada." *Vector-Borne and Zoonotic Diseases* 16(4): 215–222.

(CMHA) Canadian Mental Health Association. 2008. *Mental Health Promotion in Ontario: A Call to Action*. https://ontario.cmha.ca/documents/mental-health-promotion-in-ontario-a-call-to-action/

Condon, S., J. McDermid. 2014. *Dying on the Streets: Homeless Deaths in British Columbia*. Street Corner Media Foundation.

Cruikshank, J. 2007. *Do Glaciers Listen? Local knowledge, colonial encounters, and social imagination*. Vancouver, B.C.: UBC Press.

Cunsolo, A., & N. R. Ellis. 2018. "Ecological grief as a mental health response to climate change-related loss." *Nature Climate Change* 8(4): 275–281. https://doi.org/10.1038/s41558-018-0092-2

de Oliveira, C., S. Weir, J. Rangrej, M. D. Krahn, N. Mittmann, J. S. Hoch, K. K. W. Chan, & S. Peacock. 2018. "The economic burden of cancer care in Canada: a population-based cost study." *CMAJ Open* 6(1): E1–E10. https://doi.org/10.9778/cmajo.20170144

Department of Finance Canada. 2019. *Federal Budget*. Government of Canada. Ottawa, ON. https://www.canada.ca/en/department-finance/services/publications/federal-budget.html

Do, M. T., M. Fréchette, S. McFaull, B. Denning, M. Ruta, & W. Thompson. 2013. "Injuries in the North — analysis of 20 years of surveillance data collected by the Canadian Hospitals Injury Reporting and Prevention Program." *IJCH* 72:1.

Dodd, W., P. Scott, C. Howard, C. Scott, C. Rose, A. Cunsolo, & J. Orbinski. 2018. "Lived experience of a record wildfire season in the Northwest Territories, Canada." *Canadian Journal of Public Health* 109(3): 327–337.

Doiron, D., E. M. Setton, K. Shairsingh, M. Brauer, P. Hystad, N. A. Ross, & J. R. Brook. 2020. "Healthy built environment: Spatial patterns and relationships of multiple exposures and deprivation in Toronto, Montreal and Vancouver." *Environment International* 143 (June). https://doi.org/10.1016/j.envint.2020.106003

Dominey-Howes, D., A. Gorman-Murray, & S. McKinnon. 2014. "Queering disasters: on the need to account for LGBTI experiences in natural disaster contexts." *Gender, Place & Culture* 21(7): 905–918. https://doi.org/10.1080/0966369x.2013.802673

Dumic, I., & E. Severnini. 2018. "'Ticking Bomb': The impact of climate change on the incidence of Lyme disease." *Canadian Journal of Infectious Diseases and Medical Microbiology* Volume 2018. https://doi.org/10.1155/2018/5719081

Durkalec, A., C. Furgal, M. W. Skinner, & T. Sheldon. 2015. "Climate change influences on environment as a determinant of Indigenous health: Relationships to place, sea ice, and health in an Inuit community." *Social Science & Medicine* 136: 17–26.

Ebi, K. L., T. Hasegawa, K. Hayes, A. Monaghan, S. Paz, & P. Berry. 2018. "Health risks of warming of 1.5° C, 2° C, and higher, above pre-industrial temperatures." *Environmental Research Letters* 13(6): 63007.

Ebi, K. L., & J. J. Hess. 2020. “Health risks due to climate change: Inequity in causes and consequences.” *Health Affairs* 39(12): 2056–2062. https://doi.org/10.1377/hlthaff.2020.01125

Ebi, K. L., & D. Mills. 2013. “Winter mortality in a warming climate: a reassessment.” *Wiley Interdisciplinary Reviews: Climate Change* 4(3): 203–212.

(ECCC) Environment and Climate Change Canada. 2018a. *Canadian Environmental Sustainability Indicators: Air quality*. Government of Canada. https://canada.ca/en/environment-climate-change/services/environmental-indicators/air-quality

(ECCC) Environment and Climate Change Canada. 2018b. *Pan-Canadian Framework on Clean Growth and Climate Change: Second Annual Synthesis Report on the Status of Implementation*. Government of Canada. http://publications.gc.ca/collections/collection_2018/eccc/En1-77-2018-eng.pdf

(ECCC) Environment and Climate Change Canada. 2019. *Pan-Canadian Framework on Clean Growth and Climate Change: Third Annual Synthesis Report on the Status of Implementation*. Government of Canada Canada. http://publications.gc.ca/collections/collection_2020/eccc/En1-77-2019-eng.pdf

Ellis, N. R., & G. A. Albrecht. 2017. “Climate change threats to family farmers’ sense of place and mental wellbeing: A case study from the Western Australian Wheatbelt.” *Social Science & Medicine* 175: 161–168. https://doi.org/https://doi.org/10.1016/j.socscimed.2017.01.009

Enarson, E. 1999. “Violence Against Women in Disasters: A Study of Domestic Violence Programs in the United States and Canada.” *Violence Against Women* 5(7): 742–768. https://doi.org/10.1177/10778019922181464

(ESDC) Employment and Social Development Canada. 2019. *Housing First*. Government of Canada. Ottawa, ON. https://www.canada.ca/en/employment-social-development/programs/homelessness/resources/housing-first.html

Expert Panel on Climate Change Adaptation and Resilience Results. 2018. *Measuring Progress on Adaptation and Climate Resilience: Recommendations to the Government of Canada*. Environment Climate Change Canada.

Feltmate, B., & M. Moudrak. 2016. *Climate Change and the Preparedness of Canadian Provinces and Yukon to Limit Potential Flood Damage*. Intact Centre on Climate Adaptation, University of Waterloo. https://www.intactcentreclimateadaptation.ca/wp-content/uploads/docs/Climate%20Change%20and%20the%20Preparedness%20of%20Canadian%20Provinces%20and%20Yukon%20%28Oct%2031%202016%29.pdf

Flouris, A. D., P. C. Dinas, L. G. Ioannou, L. Nybo, G. Havenith, G. P. Kenny, & T. Kjellstrom. 2018. “Workers’ health and productivity under occupational heat strain: a systematic review and meta-analysis.” *The Lancet Planetary Health* 2(12): e521–e531.

Ford, J. D., A. Cunsolo Willox, S. Chatwood, C. Furgal, S. Harper, I. Mauro, & T. Pearce. 2014. “Adapting to the Effects of Climate Change on Inuit Health.” *American Journal of Public Health* 104: e9–e17. https://doi.org/10.2105/ajph.2013.301724

Ford, J. D., D. G. Clark, & A. Naylor. 2019a. “Food insecurity in Nunavut: Are we going from bad to worse?” *CMAJ* 191(20): e550–e551. https://doi.org/10.1503/cmaj.190497

Ford, J. D., D. G. Clark, T. Pearce, L. Berrang-Ford, L. Copland, J. Dawson, M. New, & S. L. Harper. 2019b. “Changing access to ice, land and water in Arctic communities.” *Nature Climate Change* 9(4): 335–339. https://doi.org/10.1038/s41558-019-0435-7

Ford, J. D., J. Labbé, M. Flynn, M. Araos, & I. R. Team. 2017. “Readiness for climate change adaptation in the Arctic: a case study from Nunavut, Canada.” *Climatic Change* 145(1–2): 85–100.

Ford, J. D., G. McDowell, J. Shirley, M. Pitre, R. Siewierski, W. Gough, F. Duerden, T. Pearce, P. Adams, & S. Statham. 2013. “The Dynamic Multiscale Nature of Climate Change Vulnerability: An Inuit Harvesting Example.” *Annals of the Association of American Geographers* 103(5): 1193–1211. https://doi.org/10.1080/00045608.2013.776880

Ford, J. D., T. Pearce, & G. McDowell. 2015. “The adaptation challenge in the Arctic.” *Nature Climate Change* 5(12): 1046–1053.

Gaetz, S., F. Scott, & T. Gulliver. 2013. *Housing First in Canada*. Canadian Homelessness Research Network. http://www.homelesshub.ca/sites/default/files/HousingFirstInCanada.pdf

Gasmi, S., N. H. Ogden, L. R. Lindsay, S. Burns, S. Fleming, J. Badcock, S. Hanan, C. Gaulin, M. A. Leblanc, & C. Russell. 2017. “Emerging Infections: Surveillance for Lyme disease in Canada, 2009–2015.” *Canada Communicable Disease Report* 43(10): 194.

Gearhart, S., M. Perez-Patron, T. A. Hammond, D. W. Goldberg, A. Klein, & J. A. Horney. 2018. “The Impact of Natural Disasters on Domestic Violence: An Analysis of Reports of Simple Assault in Florida (1999-2007).” *Violence and Gender* 5(2): 87–92. https://doi.org/10.1089/vio.2017.0077

Ghazali, D. A., M. Guericolas, F. Thys, F. Sarasin, P. Arcos González, & E. Casalino. 2018. “Climate change impacts on disaster and emergency medicine focusing on mitigation disruptive effects: An international perspective.” *International Journal of Environmental Research and Public Health* 15(7): 1–13. https://doi.org/10.3390/ijerph15071379

Graveland, B. 2014. “2013 Alberta flood credited with rises in domestic violence, stress.” *CTV News,* June 25 2014. https://www.ctvnews.ca/canada/increased-domestic-violence-and-stress-in-aftermath-of-last-year-s-alberta-floods-1.1885861

Guo, E. X., A. Sweetman, & G. E. Guindon. 2020. “Socioeconomic differences in prescription drug supplemental coverage in Canada: A repeated cross-sectional study.” *Health Policy* 124(3): 252–260. https://doi.org/10.1016/j.healthpol.2019.12.007

Guttmann A., S. Gandhi, S. Wanigaratne, H. Lu, L.E. Ferreira-Legere, J. Paul, P. Gozdyra, T. Campbell, H. Chung, K. Fung, B. Chen, J. C. Kwong, L. Rosella, B. R. Shaw, N. Saunders, J. M. Patterson, S.E. Bronskill, M. Azimaee, M. J. Vereulen, & M. J. Schull. 2020. *COVID-19 in Immigrants, Refugees and Other Newcomers in Ontario: Characteristics of Those Tested and Those Confirmed Positive, as of June 13, 2020.* ICES. https://www.ices.on.ca/Publications/Atlases-and-Reports/2020/COVID-19-in-Immigrants-Refugees-and-Other-Newcomers-in-Ontario

Haider, W., D. Knowler, R. Trenholm, J. Moore, P. Bradshaw, & K. Lertzman. 2019. “Climate Change, Increasing Forest Fire Incidence and the Value of Visibility: Evidence from British Columbia, Canada.” *Canadian Journal of Forest Research* 49(10).

Harun, N.-S., P. Lachapelle, & J. Douglass. 2019. “Thunderstorm-triggered asthma: what we know so far.” *Journal of Asthma and Allergy* 12: 101–108.

Hayes, K., P. Berry, & K. L. Ebi. 2019. “Factors influencing the mental health consequences of climate change in Canada.” *International Journal of Environmental Research and Public Health* 16(9). https://doi.org/10.3390/ijerph16091583

Hayes, K., G. Blashki, J. Wiseman, S. Burke, & L. Reifels. 2018. “Climate change and mental health: Risks, impacts and priority actions.” *International Journal of Mental Health Systems* 12(1): 28. https://doi.org/10.1186/s13033-018-0210-6

Healey, G. K., K. M. Magner, R. Ritter, R. Kamookak, A. Aningmiuq, B. Issaluk, K. Mackenzie, L. Allardyce, A. Stockdale, & P. Moffit. 2011. “Community perspectives on the impact of climate change on health in Nunavut, Canada.” *Arctic* 64(1): 89–97.

Health Canada. 2019. *Health Impacts of Air Pollution in Canada: Estimates of Morbidity and Premature Mortality Outcomes, 2019 Report*. Government of Canada. Ottawa, ON.

Health Canada. 2020. “Risk of Lyme disease to Canadians.” Government of Canada. Ottawa, ON. https://www.canada.ca/en/public-health/services/diseases/lyme-disease/risk-lyme-disease.html

Hess, J. J., M. Eidson, J. E. Tlumak, K. K. Raab, & G. Luber. 2014. “An evidence-based public health approach to climate change adaptation.” *Environmental Health Perspectives* 122(11): 1177.

Hess, J. J., J. N. Malilay, & A. J. Parkinson. 2008. “Climate Change. The Importance of Place.” *American Journal of Preventive Medicine* 35(5): 468–478. https://doi.org/10.1016/j.amepre.2008.08.024

Hetherington, E., S. McDonald, M. Wu, & S. Tough. 2018. “Risk and protective factors for mental health and community cohesion after the 2013 Calgary flood.” *Disaster Medicine and Public Health Preparedness* 12(4): 470–477. https://doi.org/10.1017/dmp.2017.91

Ho, H. C., A. Knudby, B. B. Walker, & S. B. Henderson. 2017. “Delineation of spatial variability in the temperature-mortality relationship on extremely hot days in greater Vancouver, Canada.” *Environmental Health Perspectives* 125(1): 66–75.

Human Rights Watch. 2020. “*My Fear Is Losing Everything”: The Climate Crisis and First Nations’ Right to Food in Canada*. https://www.hrw.org/report/2020/10/21/my-fear-losing-everything/climate-crisis-and-first-nations-right-food-canada#

Huntington, H. P., S. Gearheard, L. K. Holm, G. Noongwook, M. Opie, & J. Sanguya. 2017. “Sea ice is our beautiful garden: indigenous perspectives on sea ice in the Arctic.” In *Sea Ice, Third Edition,* ed. D. N. Thomas. Hoboken, NJ: Wiley.

(INSPQ) Institut National de Santé Publique du Québec. 2018. *Rapport de Surveillance de la maladie de Lyme: Année 2017*. Gouvernement du Québec. Quebec City, QC. https://www.canada.ca/fr/sante-publique/services/maladies/maladie-lyme/surveillance-maladie-lyme.html

(IPCC) Intergovernmental Panel on Climate Change. 2013. *Climate Change 2013: The Physical Science Basis, Contributions of Working Group I to The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change*.

(ITK) Inuit Tapiriit Kanatami. 2019. *National Inuit Climate Change Strategy*. https://www.itk.ca/national-inuit-climate-change-strategy/

Jong, M., I. Mendez, & R. Jong. 2019. “Enhancing access to care in northern rural communities via telehealth.” *International Journal of Circumpolar Health* 78(2). https://doi.org/10.1080/22423982.2018.1554174

Karetak, J., F. Tester, & S. Tagalik. 2017. *What Inuit Have Always Known to Be True.* Fernwood Publishing.

Kinney, P. L., J. Schwartz, M. Pascal, E. Petkova, A. Le Tertre, S. Medina, & R. Vautard. 2015. “Winter season mortality: will climate warming bring benefits?” *Environmental Research Letters* 10(6): 64016.

Kirchmeier-Young, M. C., N. P. Gillett, F. W. Zwiers, A. J. Cannon, & F. S. Anslow. 2019. “Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season.” *Earth’s Future* 7(1): 2–10. https://doi.org/10.1029/2018EF001050

Kjellstrom, T., D. Briggs, C. Freyberg, B. Lemke, M. Otto, & O. Hyatt. 2016. “Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts.” *Annual Review of Public Health* 37: 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740

Kowalewski, K., J. D. McLennan, & P. J. McGrath. 2011. “A preliminary investigation of wait times for child and adolescent mental health services in Canada.” *Journal of the Canadian Academy of Child and Adolescent Psychiatry* 20(2): 112–119.

Kreatsoulas, C., & S. S. Anand. 2010. “The impact of social determinants on cardiovascular disease.” *Canadian Journal of Cardiology* 26: 8C-13C. https://doi.org/10.1016/S0828-282X(10)71075-8

Labbé, J., J. D. Ford, M. Araos, & M. Flynn. 2017. “The government-led climate change adaptation landscape in Nunavut, Canada.” *Environmental Reviews* 25(1): 12–25.

Latimer, E. A., D. Rabouin, Z. Cao, A. Ly, G. Powell, T. Aubry, J. Distasio, S. W. Hwang, J. M. Somers, A. M. Bayoumi, C. Mitton, E. E. M. Moodie, & P. N. Goering. 2020. “Cost-effectiveness of housing first with assertive community treatment: Results from the Canadian at home/chez soi trial.” *Psychiatric Services* 71(10): 1020–1030. https://doi.org/10.1176/APPI.PS.202000029

Lawson, M. 2019. “The Science of the Sacred: Bridging Global Indigenous Medicine Systems and Modern Scientific Principles.” *Whispering Wind* 47(3): 42.

Le Bris, A., K. E. Mills, R. A. Wahle, Y. Chen, M. A. Alexander, A. J. Allyn, J. G. Schuetz, J. D. Scott, & A. J. Pershing. 2018. “Climate vulnerability and resilience in the most valuable North American fishery.” *Proceedings of the National Academy of Sciences of the United States of America* 115(8): 1831–1836. https://doi.org/10.1073/pnas.1711122115

Leung, K. H. Y., C. A. Arnillas, V. Y. S. Cheng, W. A. Gough, & G. B. Arhonditsis. 2020. “Seasonality patterns and distinctive signature of latitude and population on ozone concentrations in Southern Ontario, Canada.” *Atmospheric Environment* 246 (February): 118077.

Lim, K.-L., P. Jacobs, A. Ohinmaa, & C. S. Dewa. 2008. “A new population-based measure of the economic burden of mental illness in Canada.” *Chronic Diseases in Canada* 28(3).

Limaye, V. S., W. Max, J. Constible, & K. Knowlton. 2019. “Estimating the Health-Related Costs of 10 Climate-Sensitive U.S. Events During 2012.” *GeoHealth* 3(9): 245–265. https://doi.org/10.1029/2019GH000202

Liu, J. C., G. Pereira, S. A. Uhl, M. A. Bravo, & M. L. Bell. 2015. “A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke.” *Environmental Research* 136: 120–132.

Lucyk, K., & L. McLaren. 2017. “Taking stock of the social determinants of health: A scoping review.” *PLOS ONE* 12(5): e0177306. https://doi.org/10.1371/journal.pone.0177306

Ly, A., & E. Latimer. 2015. “Housing First impact on costs and associated cost offsets: A review of the literature.” *Canadian Journal of Psychiatry* 60(11): 475–487. https://doi.org/10.1177/070674371506001103

Marmot, M. 2005. “Social determinants of health inequalities.” *The Lancet* 365(9464): 1099–1104. https://doi.org/10.1016/S0140-6736(05)71146-6

Marshall-Catlin, E., T. Bushnik, & M. Tjepkema. 2019. Health Reports Trends in mortality inequalities among the adult household population. Statistics Canada. Ottawa, ON.

Martin, D., A. P. Miller, A. Quesnel-Vallée, N. R. Caron, B. Vissandjée, & G. P. Marchildon. 2018. “Canada’s universal health-care system: achieving its potential.” *The Lancet* 391(10131): 1718–1735. https://doi.org/10.1016/S0140-6736(18)30181-8

Martin, S. L., S. Cakmak, C. A. Hebbern, M. L. Avramescu, & N. Tremblay. 2012. “Climate change and future temperature-related mortality in 15 Canadian cities.” *International Journal of Biometeorology* 56(4): 605–619. https://doi.org/10.1007/s00484-011-0449-y

Matz, C. J., M. Egyed, G. Xi, J. Racine, R. Pavlovic, R. Rittmaster, S. B. Henderson, & D. M. Stieb. 2020. “Health impact analysis of PM2.5 from wildfire smoke in Canada (2013–2015, 2017–2018).” *Science of the Total Environment* 725: 138506.

McDermott, S., A. Harding, & J. Randle. 2019. *The Characteristics of Shelter Residents*. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/75f0002m/75f0002m2019004-eng.htm

McDowell, G. 2020. “Why mountains matter in Canada.” *Canadian Geographic*. https://www.canadiangeographic.ca/article/why-mountains-matter-canada

McKelvey, L., & H. Heacock. 2017. “Environmental health officers and climate change adaptation in British Columbia.” *BCIT Environmental Public Health Journal* 2: 1–14. https://doi.org/10.47339/ephj.2017.76

Metropolitan Transportation Commission. 2017. “Ozone Concentrations.” https://www.vitalsigns.mtc.ca.gov/ozone-concentrations

Middleton, J., A. Cunsolo, A. Jones-Bitton, C. J. Wright, & S. L. Harper. 2020. "Indigenous mental health in a changing climate: A systematic scoping review of the global literature." *Environmental Research Letters* 15(5). https://doi.org/10.1088/1748-9326/ab68a9

(MMIWG) National Inquiry into Missing and Murdered Indigenous Women and Girls. 2019. *Reclaiming Power and Place: The Final Report of the National Inquiry into Missing and Murdered Indigenous Women and Girls*.

Murage, P., S. Hajat, & R. S. Kovats. 2017. "Effect of night-time temperatures on cause and age-specific mortality in London." *Environmental Epidemiology* 1(2): e005. https://doi.org/10.1097/EE9.0000000000000005

Nader, F., F. Kolahdooz, & S. Sharm. 2017. "Assessing health care access and use among indigenous peoples in Alberta: A systematic review." *Journal of Health Care for the Poor and Underserved* 28(4): 1286–1303. https://doi.org/10.1353/hpu.2017.0114

Native Women's Association of Canada. 2020. *Toolkit — Impact of Climate Change on Indigenous Women, Girls, Gender-Diverse, and Two-Spirit People*.

Nelson, S. E., & K. Wilson. 2017. "The mental health of Indigenous peoples in Canada: A critical review of research." *Social Science and Medicine* 176: 93–112. https://doi.org/10.1016/j.socscimed.2017.01.021

Neria, Y, N., & S. Galea. 2008. "Post-traumatic stress disorder following disasters: a systematic review." *Psychological medicine* 38(4): 467–480. https://doi.org/10.1017/S0033291707001353

Ness, R., D. Sawyer, & R. Street. 2020. "Climate Impacts Are Getting Worse. Canada Must Adapt." Canadian Institute for Climate Choices. https://climatechoices.ca/climate-impacts-are-getting-worse-canada-must-adapt/

Neufeld, H. T., C. A. M. Richmond, & Southwest Ontario Aboriginal Health Access Centre. 2017. "Impacts of place and social spaces on traditional food systems in southwestern Ontario." *International Journal of Indigenous Health* 12(1): 93. https://doi.org/10.18357/ijih112201716903

(NRCan) Natural Resources Canada. 2020. *The State of Canada's Forests. Annual Report 2020.* Government of Canada. Ottawa, ON. https://cfs.nrcan.gc.ca/publications?id=40219&lang=en_CA

(OAG) Office of the Auditor General. 2017. "Civil aviation infrastructure in the North — Transport Canada." In *Reports of the Auditor General of Canada to the Parliament of Canada*. Government of Canada. Ottawa, ON.

(OAG) Office of the Auditor General. 2018. *Perspectives on Climate Change Action in Canada — A Collaborative Report from Auditors General*. Government of Canada. Ottawa, ON.

Ogden, N. 2008. "Risk maps for range expansion of the Lyme disease vector, *Ixodes scapularis*, in Canada now and with climate change." *International Journal of Health Geographics* 7: 24. https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-7-24

Ogden, N., & P. Gachon. 2019. "Climate change and infectious diseases: What can we expect?" *Canada Communicable Disease Report* 45(4): 76–80. https://doi.org/10.14745/ccdr.v45i04a01

Ogden, N. H., L. R. Lindsay, M. Morshed, P. N. Sockett, & H. Artsob. 2009. "The emergence of Lyme disease in Canada." *CMAJ* 180(12): 1221–1224. https://doi.org/10.1503/cmaj.080148

Ogden, N. H., A. Maarouf, I. K. Barker, M. Bigras-Poulin, L. R. Lindsay, M. G. Morshed, C. J. O'Callaghan, F. Ramay, D. Waltner-Toews, & D. F. Charron. 2005. "Climate change and the potential for range expansion of the Lyme disease vector *Ixodes scapularis* in Canada." *International Journal for Parasitology* 36(1): 63–70. https://doi.org/10.1016/j.ijpara.2005.08.016

(OMH) Ontario Ministry of Health. 2020. *COVID-19 Infection in Toronto: Ethno-racial Identity and Income*. Government of Ontario. Toronto, ON.

Orlov, A., J. Sillmann, K. Aunan, T. Kjellstrom, & A. Aaheim. 2020. "Economic costs of heat-induced reductions in worker productivity due to global warming." *Global Environmental Change* 63.

Osofsky, H. J., J. D. Osofsky, J. Arey, M. E. Kronenberg, T. Hansel, & M. Many. 2011. "Hurricane Katrina's first responders: The struggle to protect and serve in the aftermath of the disaster." *Disaster Medicine and Public Health Preparedness* 5(S2): S214–S219. https://doi.org/10.1001/dmp.2011.53

Parkinson, D. 2019. "Investigating the Increase in Domestic Violence Post Disaster: An Australian Case Study." *Journal of Interpersonal Violence* 34(11): 2333–2362. https://doi.org/10.1177/0886260517696876

Patel, A. 2019. "Access to Mental Healthcare in Indigenous Communities Across Canada." *Global Health: Annual Review* 1(4).

Paterson, J., P. Berry, K. Ebi, & L. Varangu. 2014. "Health care facilities resilient to climate change impacts." *International Journal of Environmental Research and Public Health* 11(12): 13097–13116. https://doi.org/10.3390/ijerph111213097

Patterson, A. C., & G. Veenstra. 2016. "Black-White health inequalities in Canada at the intersection of gender and immigration." *Canadian Journal of Public Health* 107(3): e278–e284. https://doi.org/10.17269/CJPH.107.5336

(PBO) Office of the Parliamentary Budget Officer. 2017. *FSR 2017 — Provincial-Territorial Health Care Cost Drivers*.

(PHAC) Public Health Agency of Canada. 2010. *Economic Burden of Illness in Canada, 2010*. Government of Canada. Ottawa, ON. https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/science-research/economic-burden-illness-canada-2010/economic-burden-illness-canada-2010.pdf

(PHAC) Public Health Agency of Canada. 2017. *Science Narrative: Climate Change Impacts on the Health of Canadians*. Government of Canada. Ottawa, ON. http://publications.gc.ca/collections/collection_2017/aspc-phac/HP5-122-2017-eng.pdf

(PHAC) Public Health Agency of Canada. 2018. *Key Health Inequalities in Canada: A National Portrait*. Government of Canada. Ottawa, ON.

(PHAC) Public Health Agency of Canada. 2020. *Surveillance of Lyme Disease*. Government of Canada. Ottawa, ON.

Phillips-Beck, W., R. Eni, J. G. Lavoie, K. A. Kinew, G. K. Achan, & A. Katz. 2020. "Confronting racism within the Canadian healthcare system: Systemic exclusion of First Nations from quality and consistent care." *International Journal of Environmental Research and Public Health* 17(22): 1–20. https://doi.org/10.3390/ijerph17228343

Pollock, N. J., G. K. Healey, M. Jong, J. E. Valcour, & S. Mulay. 2018. "Tracking progress in suicide prevention in Indigenous communities: A challenge for public health surveillance in Canada." *BMC Public Health* 18(1): 1–17. https://doi.org/10.1186/s12889-018-6224-9

Pong, R. W., & J. R. Pitblado. 2005. *Geographic Distribution of Physicians in Canada: Beyond How Many and Where*. Canadian Institute for Health Information. Ottawa, ON. https://secure.cihi.ca/free_products/Geographic_Distribution_of_Physicians_FINAL_e.pdf

Poremski, D., J. Distasio, S. W. Hwang, & E. Latimer. 2015. "Employment and income of people who experience mental illness and homelessness in a large Canadian sample." *Canadian Journal of Psychiatry* 60(9): 379–385. https://doi.org/10.1177/070674371506000902

Power, E. M. 2008. "Conceptualizing food security for Aboriginal people in Canada." *Canadian Journal of Public Health* 99(2): 95–97. https://doi.org/10.1007/bf03405452

Prairie Climate Centre. 2019. *Climate Atlas of Canada*.

Public Health Ontario. 2020a. "Lyme Disease." https://www.publichealthontario.ca/en/diseases-and-conditions/infectious-diseases/vector-borne-zoonotic-diseases/lyme-disease

Public Health Ontario. 2020b. *Rapid Review: Substance Use-related Harms and Risk Factors During Periods of Disruption*. https://www.publichealthontario.ca/-/media/documents/ncov/main/2020/08/substance-use-related-harms-disruption.pdf?la=en

Rao, S. 2020. "A natural disaster and intimate partner violence: Evidence over time." *Social Science & Medicine* 247: 112804. https://doi.org/https://doi.org/10.1016/j.socscimed.2020.112804

Ready, E., & P. Collings. 2020. "'All the problems in the community are multifaceted and related to each other': Inuit concerns in an era of climate change." *American Journal of Human Biology* e23516. https://doi.org/https://doi.org/10.1002/ajhb.23516

Reid, C. E., M. Brauer, F. H. Johnston, M. Jerrett, J. R. Balmes, & C. T. Elliott. 2016. "Critical review of health impacts of wildfire smoke exposure." *Environmental Health Perspectives* 124(9): 1334–1343.

Rezayat, A. A., S. Sahebdel, S. Jafari, A. Kabirian, A. M. Rahnejat, R. H. Farahani, R. Mosaed, & M. G. Nour. 2020. "Evaluating the Prevalence of PTSD among Children and Adolescents after Earthquakes and Floods: a Systematic Review and Meta-Analysis." *Psychiatric Quarterly* 91(4): 1265–1290. https://doi.org/10.1007/s11126-020-09840-4

Ribot, J. 2014. "Cause and response: vulnerability and climate in the Anthropocene." *Journal of Peasant Studies* 41(5): 667–705.

Richards, G., J. Frehs, E. Myers, & M. Van Bibber. 2019. "The climate change and health adaptation program: Indigenous climate leaders' championing adaptation efforts." *Health Promotion and Chronic Disease Prevention in Canada* 39(4): 127–130. https://doi.org/10.24095/hpcdp.39.4.03

Richmond, C., R. B. Kerr, H. Neufeld, M. Steckley, K. Wilson, & B. Dokis. 2021. "Supporting food security for Indigenous families through the restoration of Indigenous foodways." *Canadian Geographer* 65(1): 97-109. https://doi.org/10.1111/cag.12677

Richmond, C. A. M., & N. A. Ross. 2009. "The determinants of First Nation and Inuit health: A critical population health approach." *Health and Place* 15(2): 403–411. https://doi.org/10.1016/j.healthplace.2008.07.004

Rinner, C., & M. Hussain. 2011. "Toronto's urban heat island — Exploring the relationship between land use and surface temperature." *Remote Sensing* 3(6): 1251–1265. https://doi.org/10.3390/rs3061251

Robinne, F. N., K. D. Bladon, U. Silins, M. B. Emelko, M. D. Flannigan, M. A. Parisien, X. Wang, S. W. Kienzle, & D. P. Dupont. 2019. "A regional-scale index for assessing the exposure of drinking-water sources to wildfires." *Forests* 10(5): 1–21. https://doi.org/10.3390/f10050384

Rosenzweig, C., S. Gaffin, & L. Parshall. 2003. *Green Roofs in the New York Metropolitan Region*. Columbia University Center for Climate Systems Research & NASA Goddard Institute for Space Studies.

Sahni, V., A. N. Scott, M. Beliveau, M. Varughese, D. C. Dover, & J. Talbot. 2016. "Public health surveillance response following the southern Alberta floods, 2013." *Canadian Journal of Public Health* 107(2): e142–e148. https://doi.org/10.17269/CJPH.107.5188

Santé Montréal. 2019. *Extreme Heat: 66 Deaths in Montreal in 2018*. Gouvernement du Québec. Quebec City, QC

Sarofim, M. C., S. Saha, M. D. Hawkins, D. M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, & A. St. Juliana. 2016. "Ch. 2: Temperature-Related Death and Illness." In *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program. https://doi.org/10.7930/J0MG7MDX

Sawyer, D., R. Ness, D. G. Clark, & D. Beugin. 2020. *Tip of the Iceberg: Navigating the Known and Unknown Costs of Climate Change for Canada*. Canadian Institute for Climate Choices. https://climatechoices.ca/reports/tip-of-the-iceberg/

Schmeltz, M. T., & J. L. Gamble. 2017. "Risk characterization of hospitalizations for mental illness and/or behavioral disorders with concurrent heat-related illness." *PLoS ONE* 12(10): 1–15. https://doi.org/10.1371/journal.pone.0186509

Schnitter, R., & P. Berry. 2019. "The climate change, food security and human health nexus in Canada: a framework to protect population health." *International Journal of Environmental Research and Public Health* 16(14): 2531.

Scott, D., A. Minano, L. Chakraborty, D. Henstra, J. Thistlethwaite, & Y. Apajee. 2020. *Flood Risk Analysis of Canadian Health and Emergency Infrastructure*. Health Canada. Ottawa, ON.

Sellers, S. 2018. *Climate Change and Gender in Canada: A Review.* Women's Environment & Development Organization. https://wedo.org/wp-content/uploads/2018/04/GGCA-CA-RP-07.pdf

Shahidi, F. V., A. Parnia, & A. Siddiqi. 2020. "Trends in socioeconomic inequalities in premature and avoidable mortality in Canada, 1991–2016." CMAJ, 192(39), E1114–E1128. https://doi.org/10.1503/cmaj.191723

Shapiro, E. D. 2014. "Lyme disease." *New England Journal of Medicine* 370(18): 1724–1731.

Smart Prosperity. 2020. *Thinking about Health Co-benefits in a Green Recovery*.

Smetanin, P., C. Briante, D. Stiff, S. Ahmad, & M. Khan. 2015. *The Life and Economic Impact of Major Mental Illnesses in Canada: 2011 to 2041.* RiskAnalytics, on behalf of Mental Health Commission of Canada.

Smit, B., I. Burton, R. J. T. Klein, & J. Wandel. 2000. "An anatomy of adaptation to climate change and variability." *Climatic Change* 45(1): 223–251. https://doi.org/10.1023/A:1005661622966

Statistics Canada. 2013. *Canadian Community Health Survey: Annual Component*.

Statistics Canada. 2016. *Family Violence in Canada: A Statistical Profile, 2016*. https://www150.statcan.gc.ca/n1/pub/85-002-x/2018001/article/54893-eng.htm

Statistics Canada. 2019. *Population Projections for Canada (2018–2068), Provinces and Territories (2018–2043): Technical Report on Methodology and Assumptions*. https://www150.statcan.gc.ca/n1/pub/91-620-x/91-620-x2019001-eng.htm

Stewart, R. E., D. Betancourt, J. B. Davies, D. Harford, Y. Klein, R. Lannigan, L. Mortsch, E. O'Connell, K. Tang, & P. H. Whitfield. 2017. "A multi-perspective examination of heat waves affecting Metro Vancouver: Now into the future." *Natural Hazards* 87(2): 791–815.

Stockwell, T., & M. Young. 2018. *Canadian Substance Use Costs and Harms (2007-2014)*. Canadian Centre on Substance Use and Addiction. https://www.ccsa.ca/sites/default/files/2019-04/CSUCH-Canadian-Substance-Use-Costs-Harms-Report-2018-en.pdf

Streicker, J. 2016. *Yukon Climate Change Indicators and Key Findings 2015.* Northern Climate ExChange, Yukon Research Centre, Yukon College.

Suicide Prevention Resource Centre. 2008. *Sexual Minorities and Suicide Prevention*.

Sun, Q., C. Miao, M. Hanel, A. G. L. Borthwick, Q. Duan, D. Ji, & H. Li. 2019. "Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming." *Environment International* 128: 125–136.

Sutherland, G. 2016. *Healthy Brains at Work: Estimating the Impact of Workplace Mental Health Benefits and Programs*. The Conference Board of Canada.

Tan, X., S. Chen, T. Y. Gan, B. Liu, & X. Chen. 2019. "Dynamic and thermodynamic changes conducive to the increased occurrence of extreme spring fire weather over western Canada under possible anthropogenic climate change." *Agricultural and Forest Meteorology* 265: 269–279. https://doi.org/10.1016/j.agrformet.2018.11.026

Tarasuk, V., & A. Mitchell. 2020. “Household Food Insecurity in Canada.” *Topics in Clinical Nutrition* 20(4): 299–312. https://doi.org/10.1097/00008486-200510000-00003

Tester, F. J. 2010. “Mad dogs and (mostly) Englishmen: Colonial relations, commodities, and the fate of Inuit sled dogs.” *Études/Inuit/Studies* 34(2): 129–147. https://www.erudit.org/en/journals/etudinuit/2010-v34-n2-etudinuit5000473/1004073ar.pdf

Tester, F. J., & P. Irniq. 2008. “Inuit Qaujimajatuqangit: Social history, politics and the practice of resistance.” *Arctic* 61(5) 48–61.

Thien, F., P. J. Beggs, D. Csutoros, J. Darvall, M. Hew, J. M. Davies, P. G. Bardin, T. Bannister, S. Barnes, & R. Bellomo. 2018. “The Melbourne epidemic thunderstorm asthma event 2016: An investigation of environmental triggers, effect on health services, and patient risk factors.” *The Lancet Planetary Health* 2(6): e255–e263.

Thomson, M. S., F. Chaze, U. George, & S. Guruge. 2015. “Improving Immigrant Populations’ Access to Mental Health Services in Canada: A Review of Barriers and Recommendations.” *Journal of Immigrant and Minority Health* 17(6): 1895–1905. https://doi.org/10.1007/s10903-015-0175-3

(TRC) Truth and Reconciliation Commission of Canada. 2015. *Truth and Reconciliation Commission of Canada: Calls to Action*.

Tschakert, P., J. Barnett, N. Ellis, C. Lawrence, N. Tuana, M. New, C. Elrick-Barr, R. Pandit, & D. Pannell. 2017. “Climate change and loss, as if people mattered: Values, places, and experiences.” *Wiley Interdisciplinary Reviews: Climate Change* 8(5): 1–19. https://doi.org/10.1002/wcc.476

Veenstra, G., & A. C. Patterson. 2016. “Black–White Health Inequalities in Canada.” *Journal of Immigrant and Minority Health* 18(1): 51–57. https://doi.org/10.1007/s10903-014-0140-6

Vincent, L. A., X. Zhang, É. Mekis, H. Wan, & E. J. Bush. 2018. “Changes in Canada’s Climate: Trends in Indices Based on Daily Temperature and Precipitation Data.” *Atmosphere-Ocean* 56(5): 332–349. https://doi.org/10.1080/07055900.2018.1514579

Vivid Economics. 2019. *Accelerated Electrification and the GB Electricity System.* Report prepared for Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2019/05/CCC-Accelerated-Electrification-Vivid-Economics-Imperial.pdf

Waldron, I. 2018. *There’s Something in the Water: Environmental Racism in indigenous and Black Communities*. Halifax, NS: Fernwood Publishing.

Wang, X., E. Lavigne, H. Ouellette-Kuntz, & B. E. Chen. 2014. “Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behavior disorders in Toronto, Canada.” *Journal of Affective Disorders* 155(1): 154–161. https://doi.org/10.1016/j.jad.2013.10.042

Wang, X., K. Studens, M.-A. Parisien, S. W. Taylor, J.-N. Candau, Y. Boulanger, & M. D. Flannigan. 2020. “Projected changes in fire size from daily spread potential in Canada over the 21st century.” *Environmental Research Letters* 15(10): 104048.

Watts, N., W. N. Adge, P. Agnolucci, J. Blackstock, P. Byass, W. Cai, S. Chaytor, T. Colbourn, M. Collins, & A. Cooper. 2015. “Health and climate change: policy responses to protect public health.” *The Lancet* 386(10006): 1861–1914.

Watts, N., M. Amann, N. Arnell, S. Ayeb-Karlsson, J. Beagley, K. Belesova, M. Boykoff, P. Byass, W. Cai, & D. Campbell-Lendrum. 2020. “The 2020 report of The *Lancet* Countdown on health and climate change: responding to converging crises.” *The Lancet* 397(10269): 129–170.

Watts, N., M. Amann, N. Arnell, S. Ayeb-Karlsson, K. Belesova, M. Boykoff, P. Byass, W. Cai, D. Campbell-Lendrum, & S. Capstick. 2019. “The 2019 report of The *Lancet* Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *The Lancet* 394(10211): 1836–1878.

Wenzel, G. 2009. “Canadian Inuit subsistence and ecological instability—if the climate changes, must the Inuit?” *Polar Research* 28(1): 89–99.

Wenzel, G. 2013. “Inuit and Modern Hunter-Gatherer Subsistence.” *Inuit Studies* 37(2): 181–200.

(WHO) World Health Organization. 2015. *Operational Framework for Building Climate Resilient Health Systems.* World Health Organisation.

(WHO) World Health Organization. 2019. *Health and Climate Change Survey Report Tracking Global Progress*. http://apps.who.int/bookorders

Williams, L., A. Fletcher, C. Hanson, J. Neapole, & M. Pollack. 2018. *Women and Climate Change Impacts and Action in Canada: Feminist, Indigenous, and Intersectional Perspectives*. Canadian Research Institute for the Advancement of Women & the Alliance for Intergenerational Resilience. https://www.criaw-icref.ca/images/userfiles/files/Women%20and%20Climate%20Change_FINAL.pdf

Wotton, B. M., M. D. Flannigan, & G. A. Marshall. 2017. “Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada.” *Environmental Research Letters* 12(9): 95003.

Wyllie de Echeverria, V. R., & T. F. Thornton. 2019. “Using traditional ecological knowledge to understand and adapt to climate and biodiversity change on the Pacific coast of North America.” *Ambio* 48(12): 1447–1469. https://doi.org/10.1007/s13280-019-01218-6

Young, T. K., T. Tabish, S. K. Young, & G. Healey. 2019. “Patient transportation in Canada’s northern territories: patterns, costs and providers’ perspectives.” *Rural and Remote Health* 19(2): 5113. https://doi.org/10.22605/RRH5113

Yssaad, L., & A. Fields. 2018. *The Canadian Immigrant Labour Market: Recent Trends from 2006 to 2017*. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/71-606-x/71-606-x2018001-eng.htm

Zivin, J., & M. Neidell. 2014. “Temperature and the allocation of time: Implications for climate change.” *Journal of Labor Economics* 32(1): 1–26.

ACKNOWLEDGEMENTS

Staff Authors:

Dylan Clark, Senior Research Associate, Canadian Institute for Climate Choices

Ryan Ness, Adaptation Research Director, Canadian Institute for Climate Choices

Dena Coffman, Research Assistant, Canadian Institute for Climate Choices

Dale Beugin, Vice President, Research and Analysis, Canadian Institute for Climate Choices

Adaptation Panel Report Working Group:

Ashlee Cunsolo, Founding Dean, School of Arctic and Subarctic Studies, Labrador Institute of Memorial University

Daniel Scott, Executive Director, Interdisciplinary Centre on Climate Change, University of Waterloo

Deborah Harford, ACT (the Adaptation to Climate Change Team), Faculty of Environment, Simon Fraser University

Ian Mauro, Executive Director, Prairie Climate Centre

Deborah McGregor, Canada Research Chair, Indigenous Environmental Justice, York University

External Reviewers:

Sherilee Harper, Associate Professor, University of Alberta

Renée Monchalin, Assistant Professor, University of Victoria

Other Reviewers and Guidance:

Julien Bourque, Research Associate, Canadian Institute for Climate Choices

Maria Shallard, Senior Advisor, Indigenous Engagement and Research, Canadian Institute for Climate Choices

Consultant Research Team:

Jimena Eyzaguirre, ESSA Technologies Ltd.

Richard Boyd, All One Sky Foundation

Frank Poulsen, ESSA Technologies Ltd.

Matthew Siegle, ESSA Technologies Ltd.

Shelby Yamamoto, University of Alberta

Alvaro Osornio-Vargas, University of Alberta

Production Support:

Design and layout: Laurie Barnett, Graphic Designer

Proofreading: Julie Stauffer, Cadmium Red Communications (English); Edith Sans Cartier (French)

Information design by Voilà: chezVoila.com

Translation: Edgar (report text) and Sabine Monnin (figures)

Cover design: Alex Wittholz

Recommended citation:

Clark, D. G., R. Ness, D. Coffman, D. Beugin. 2021. *The Health Costs of Climate Change: How Canada Can Adapt, Prepare, and Save Lives*. Canadian Institute for Climate Choices. https://climatechoices.ca/reports/the-health-costs-of-climate-change/

This project was undertaken with the financial support of:

Environment and Climate Change Canada | Environnement et Changement climatique Canada

MORE PUBLICATIONS FROM THE INSTITUTE:

MARKING THE WAY:

How legislating climate milestones clarifies pathways to long-term goals

11 WAYS TO MEASURE CLEAN GROWTH:

Unlocking prosperity through progress on climate change, economic and social goals

TIP OF THE ICEBERG:

Navigating the known and unknown costs of climate change for Canada

CANADA'S NET ZERO FUTURE:

Finding our way in the global transition

climatechoices.ca