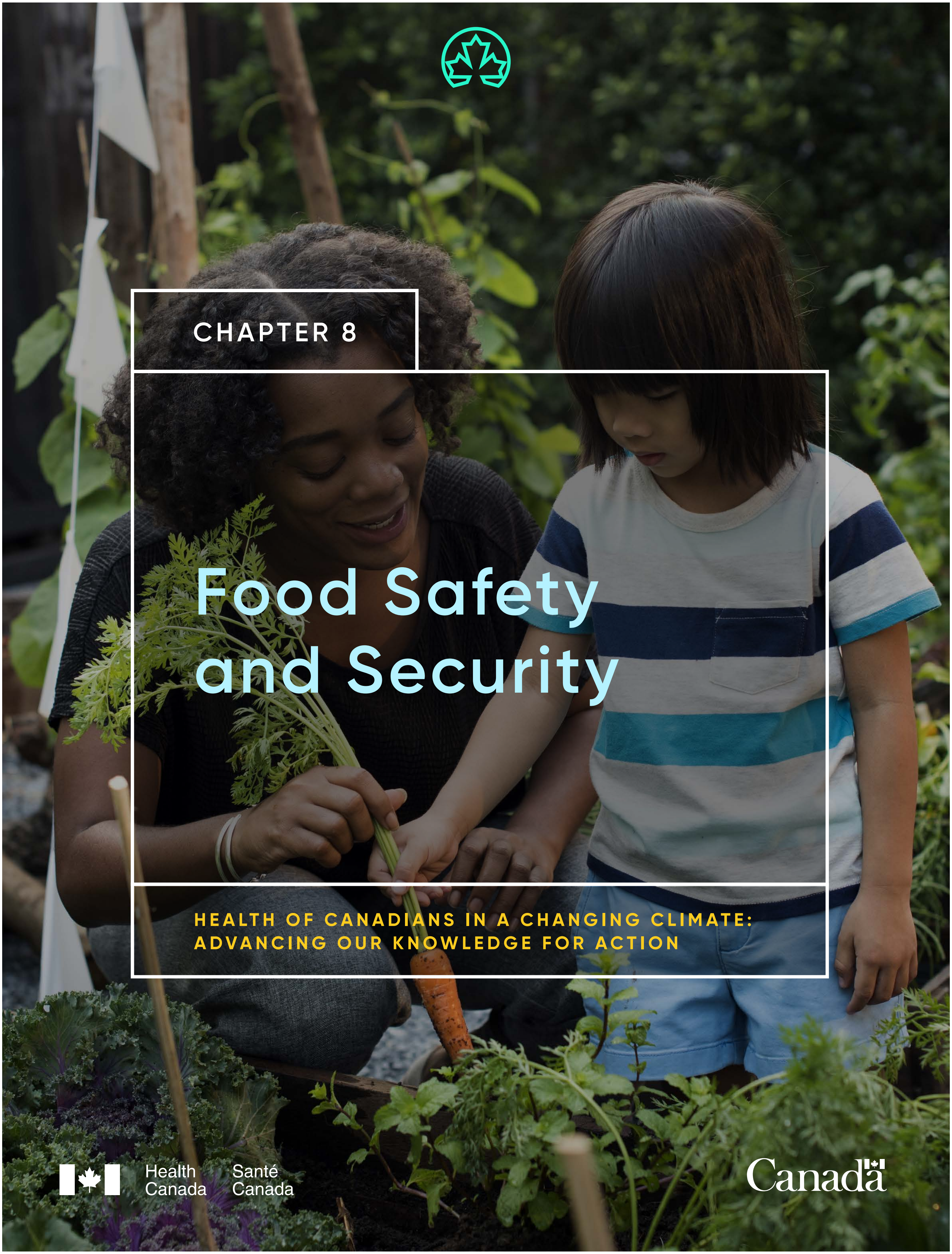


CHAPTER 8

Food Safety and Security

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Authors

Sherilee L. Harper, University of Alberta

Rebekka Schnitter, Health Canada

Contributing Authors

Aamir Fazil, Public Health Agency of Canada

Manon Fleury, Public Health Agency of Canada

James Ford, University of Leeds

Nia King, Queen's University

Alexandra Lesnikowski, Concordia University

Deborah McGregor, York University

Jaclyn Paterson, Health Canada

Ben Smith, Public Health Agency of Canada

Hannah Tait Neufeld, University of Waterloo

Acknowledgements

Amreen Babujee, University of Alberta

Katharine Neale, University of Alberta

Alexandra Sawatzky, University of Alberta

Shanaya Singh, Health Canada

Suggested Citation

Harper, S. L., Schnitter, R., Fazil, A., Fleury, M., Ford, J., King, N., Lesnikowski, A., McGregor, D., Paterson, J., Smith, B., & Neufeld, H. T. (2022). Food Security and Food Safety. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

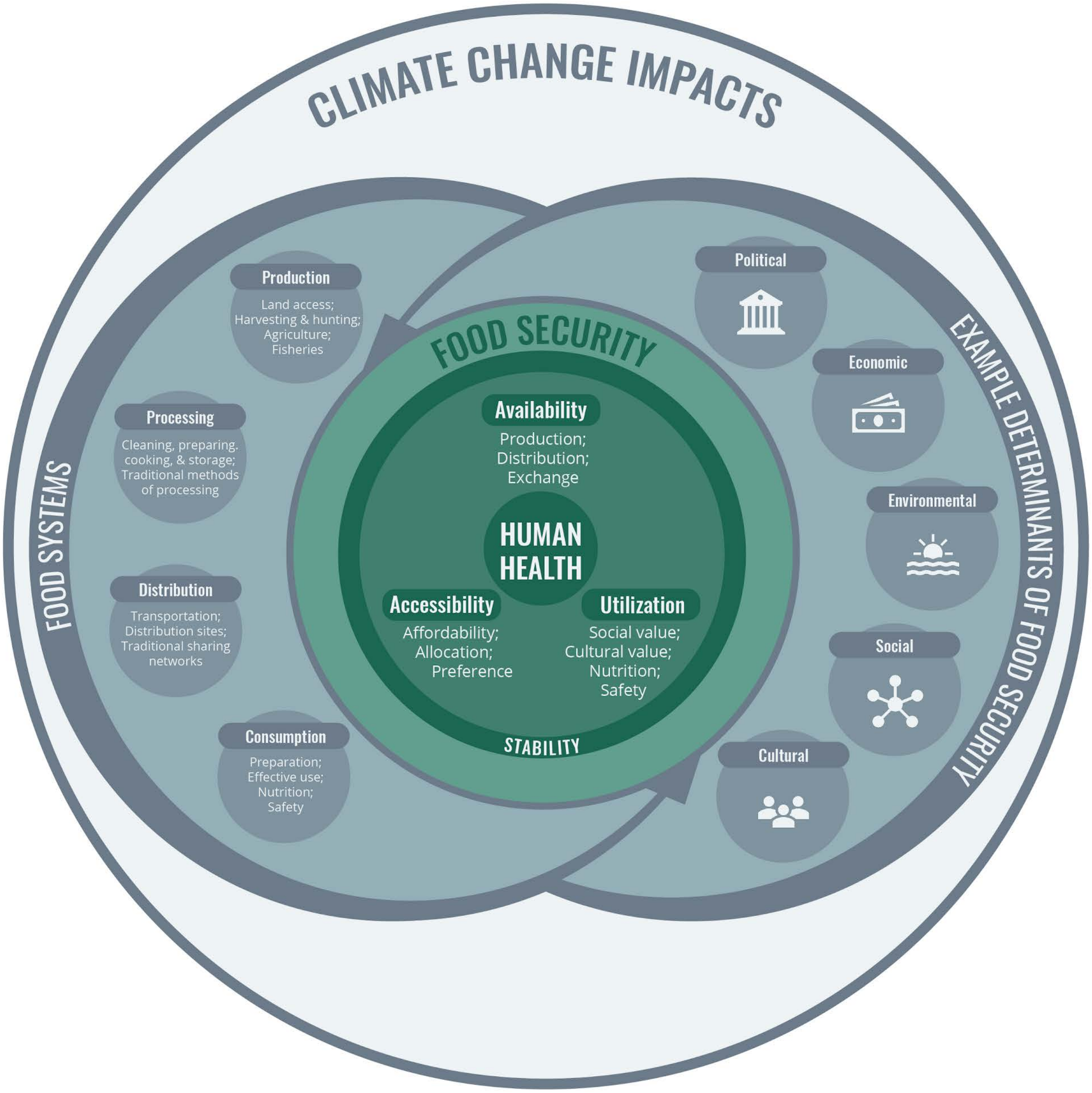
Summary

Changes in climate are affecting food security and food safety in Canada. Climate change is increasing risks of food insecurity through disruptions to food systems, rises in food prices, and negative nutritional effects. Precipitation, temperature, and extreme weather events are projected to increase the introduction of pathogens (viruses, bacteria, and parasites) to food, causing food-borne illness. Chemical contaminants that have harmful health effects may also be introduced into Canada's food systems more frequently through various climate-sensitive environmental exposure pathways. The impacts of climate change on food security and food safety will not be equitably distributed, and Canada's Northern region and Indigenous Peoples will likely experience the most severe effects. Adaptation measures include monitoring of health outcomes related to food safety; conducting vulnerability and adaptation assessments that address climate-related impacts to food security and food safety; utilizing both Western science and Indigenous knowledge; developing adaptation plans within all levels of government and in all regions, particularly in Northern Canada; conducting risk communication and education; and tackling root causes of vulnerability.

Key Messages

- Warming temperatures, changing precipitation patterns, and more frequent and severe extreme weather events will increase risks to key components of food systems in Canada, such as the production, processing, distribution, preparation, and consumption of food.
- Climate change impacts on food systems, rises in food prices, and negative nutritional effects have already negatively influenced food security and food safety, both of which have important implications for human health. Globally, climate change is projected to have negative effects on the nutritional content and overall yield of some agricultural commodities, particularly subsistence crops including grains and legumes. Changes in biodiversity from climate change may also result in nutritional challenges, for example, from declining availability of traditional food sources. As a result, climate change is projected to affect the health of Canadians by affecting the amount of nutrients they obtain from their food, as well as the stability of food availability, accessibility, and use.
- Climate change is projected to exacerbate existing food safety challenges in Canada and create new ones. Precipitation, temperature, and extreme weather events affect the introduction of pathogens to foods and their ability to grow to levels that cause food-borne illness. Climate change may also affect human behaviours, such as food handling and consumption practices (such as barbeques, picnics).

- Climate change impacts on food security and food safety vary greatly across Canada, reflecting underlying societal, cultural, environmental, and economic factors and inequities. While it is difficult to estimate the precise magnitude of current and future climate change impacts on food insecurity, these impacts are expected to exacerbate health-related risks for Canadians.
- Climate change may increase the exposure of Canadians to chemical contaminants, such as persistent organic pollutants and heavy metals that can have harmful health effects. These chemical contaminants can be introduced into Canada's food systems through various environmental exposure pathways and then accumulate in plant and animal tissues that are consumed. Many of these chemicals can exacerbate existing health risks for Canadians and create new ones, which underlines the importance of Canada's surveillance programs.
- Climate change is affecting Indigenous food systems and contributing to declining availability, accessibility, and quality of traditionally harvested foods, which play an important role in community and individual health and well-being. Climate change has already affected nutrition, mental health outcomes, and food sovereignty. Indigenous food security must be understood within the context of historical and ongoing colonialism. Indigenous self-determination and the gendered and intergenerational transmission of Indigenous knowledge are central to Indigenous food security and sovereignty and needed adaptation actions.
- Adaptation actions that increase food system resilience, including collaboration of health authorities among a broad range of food system actors and sectors, are necessary to minimize risks to human health from climate change. Efforts are underway across Canada to respond to and prepare for the impacts of climate change on food systems in order to protect and support health and well-being. Further adaptations will reduce future risks.



Conceptual framework outlining the relationships among food security, food safety, and health in a changing climate.

Overview of Climate Change Impacts on Food Safety and Security

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Food security	• Increased disruptions to food systems affecting the stability of food availability, accessibility, and use • Climate-related reductions in biological diversity in sensitive ecological environments, leading to less sustainable land and aquatic ecosystems • Modification of nutrient content and overall production of some agricultural commodities • Increased economic pressures on low-income and subsistence food users due to increasing food prices and changing availability of local and traditionally harvested foods	• Impacts on nutrition due to decreased availability of local and traditional foods • Impacts on nutrition due to effects on the amount of nutrients obtained from food • Adverse birth outcomes • Impacts on maternal health • Impacts on child development • Exacerbation of chronic diseases • Impacts on mental health and emotional well-being • Impacts on health services; for example, adults experiencing food insecurity require more health care services and are more likely to become high-cost health care users

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Food safety	• Changing climatic conditions can affect the transportation and deposition of chemical contaminants in food systems • Acute and slow-onset climate change impacts (such as changes in precipitation, temperature, and extreme weather events) can alter the occurrence and survival of microbial pathogens in food and result in increased prevalence of food-borne illness • Extended warm weather seasons can increase the risks to Canadians via increased opportunities for food mishandling (such as barbequing, picnics) and changes to food preferences based on food availability (such as extended availability of high-risk food products such as fresh produce), increasing risk of exposure to food-borne illness	• Chemical toxicity at high levels can lead to cancer, cardiovascular disorders, kidney and bone damage, negative immune system effects, developmental, endocrine disruption, reproductive disorders, cognitive, behavioural, and motor impairments; currently the levels of chemical contaminants in retail foods is monitored closely in Canada, which underlines the importance of Canada's surveillance programs in a changing climate • Microbial food-borne illnesses (giardiasis, campylobacteriosis, salmonellosis) lead to diarrhea, vomiting, stomach cramps, low-grade fever, chills, headache, muscle aches, fatigue, weight loss, loss of appetite, severe dehydration, inflammation of the brain, meningitis, liver disease, birth defects, stillbirth, and premature delivery • In severe cases, chemical or microbial food-borne illness can result in death • Impacts on health services, for example, enhanced national and international surveillance and monitoring of food-borne illness

8.1 Introduction

Climate change has widespread implications for food systems globally and in Canada, with important health consequences. These climate change impacts touch all components of food systems, including food production, processing, distribution, preparation, and consumption. Without adaptation, climate change will result in a negative net impact on global food systems (Porter et al., 2014; Smith et al., 2014; Springmann et al., 2016; IPCC, 2019a). For instance, increasing water insecurity, combined with rising crop irrigation demands due to warming temperatures and less rainfall, are projected to result in substantial global net reductions in staple crop yields (Jiménez Cisneros et al., 2014; Porter et al., 2014); decreased fisheries catch (FAO, 2015; Arnell et al., 2016); lower nutrient concentrations in staple foods (FAO, 2015); and increased global food prices (Porter et al., 2014). Such climate change impacts on global food systems have important implications for both *food security* (i.e., stable access to sufficient and nutritious food to meet dietary needs and food preferences for healthy lives) and *food safety* (i.e., access to food that is not contaminated with pathogens or chemical contaminants at levels that could lead to adverse health effects). Thus, these impacts will pose significant challenges to human health, including impacts on nutrition, mental wellness, and food-borne illnesses (Bradbear & Friel, 2013; Bowen & Ebi, 2015; Springmann et al., 2016). These health risks are substantial; globally, food-related mortality attributed to climate change is projected to "far exceed" all other climate-related health effects (WHO, 2014).

In Canada, climate change is already affecting food security and safety, particularly in the North (Berry et al., 2014a; CCA, 2014). Climate change impacts on food and agriculture, as well as health and well-being, are among the top climate change threats that are expected to lead to significant losses, damage, and/or disruptions in Canada over the next 20 years (CCA, 2019). While the impacts of climate change on food systems in Canada will be widespread, they will not be distributed equitably, with some populations, subpopulations, and regions experiencing greater barriers to adaptation and disproportionate impacts. Despite these risks, food issues have received less attention than other health outcomes in climate-health research (Smith et al., 2014; Verner et al., 2016), although research on climate change impacts on food systems and human health in Canada is beginning to increase.

This chapter explores the linkages among climate change, food systems, and human health to understand current risks and how Canadians could be affected in the future. It also examines the adaptation options available for reducing health risks. To this end, this chapter first outlines the conceptual framework used to conduct this analysis. Then, climate change impacts on food systems in the context of human health are described. Within food systems, three elements are assessed: climate change impacts on food security and related health outcomes, with specific attention to nutrition; on microbial food safety (food-borne pathogens); and on chemical food safety (chemical contaminants). The chapter then examines adaptation opportunities to reduce food-related health risks and presents illustrative case studies. The final section of this chapter highlights knowledge gaps and recommendations related to food systems and adaptation. Throughout the chapter, Boxes 8.1 to 8.6 highlight critical cross-cutting concepts and phenomena, as well as presenting case studies that showcase climate change impacts and adaptation.

8.2 Conceptual Framework and Methods

8.2.1 Conceptualizing Climate Change, Food Systems, and Human Health

This chapter is guided by a framework (Schnitter & Berry, 2019) that conceptualizes the breadth and complexity of climate change impacts on food systems and hence on human health (Figure 8.1). The framework describes the dynamic relationship among food systems, primary dimensions and determinants of food security and safety, and human health outcomes in a changing climate.

Within this framework, *food systems* consist of activities and elements spanning multiple sectors related to food production, processing, distribution, preparation, and consumption (Gregory et al., 2005; Ericksen, 2008; Anand et al., 2015; HLPE, 2017). These food system components include non-commercial and commercial production, transportation, washing, cooking, preparation, storage, consumption, and use of food (Ingram, 2009; Friel, 2019) and are often interconnected, with the activities of one component affecting the operations of others.

Food systems underpin the primary dimensions of *food security* by supporting the stability and strength of its pillars: food availability, accessibility, and use (Table 8.1) (Pinstrup-Andersen, 2013; Friel & Ford, 2015; Nelson et al., 2016). Food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). In contrast, *food insecurity* exists whenever any of these pillars are unfulfilled. Influenced by political, economic, social, and environmental factors (Ericksen, 2008), food security can be measured at different spatial and temporal scales (Gregory et al., 2005) and occurs on a spectrum (e.g., food secure, marginally food insecure, moderately food insecure, severely food insecure) (Health Canada, 2020). Food security or insecurity affects health and well-being and, thus, is a public health issue.

Food security cannot exist without *food safety*. The safety of food for human consumption can be compromised at any point in food systems, and the ingestion of contaminated food can result in adverse health effects and, in severe cases, death. Food safety systems are critical for ensuring that the food consumed by Canadians is safe to eat, and that pathogens or contaminants are not present in foods at levels that can cause harm. Two elements of food safety and their relationship to climate change are explored in this chapter: food-borne pathogens and chemical contaminants.

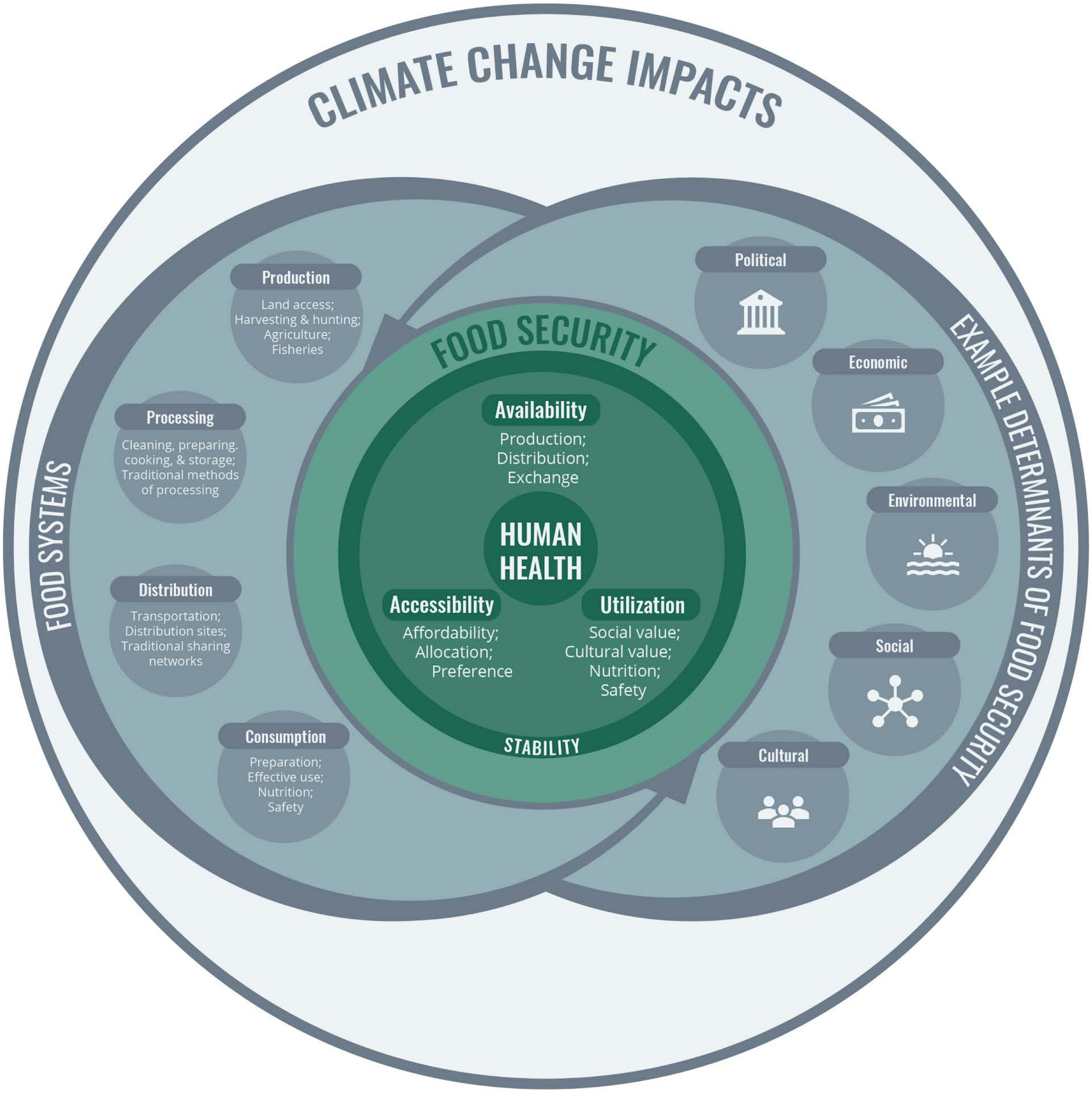


Figure 8.1 Conceptual framework outlining the relationships among food security, food safety, and health in a changing climate.

Table 8.1 Pillars of food security and their elements

FOOD SECURITY PILLARS	ELEMENTS OF PILLARS
Food availability	• Production: Amount and types of food available • Distribution: How food is made available, in what form, when, and to whom • Exchange: How much of the available food is obtained through exchange mechanisms such as food sharing, bartering, trading, purchasing, or loans
Food accessibility	• Affordability: The purchasing power of households or communities relative to the price of food; the cost associated with harvesting, hunting, and fishing of local, traditional, and/or country[1] foods • Allocation: The economic, social, and political mechanisms governing when, where, and how food can be accessed by people • Preference: Social, religious, and/or cultural norms, values, and practices that influence consumer demand for certain types of food
Food use	• Nutritional value: How much of the daily requirements of calories, macronutrients, and micronutrients are provided by the food people consume • Social value: The social, religious, and/or cultural functions and benefits that food provides • Food safety: Microbial or chemical contamination introduced during producing, processing, packaging, distribution, handling, or marketing food
Stability	• Long-term stability of food availability, accessibility, and use

Source: Adapted from Ericksen, 2008

1 Traditional Inuit food, also known as country food, is an integral part of Inuit identity and culture, is a significant source of nutrients, and contributes to individual and community health and well-being. It includes marine animals (e.g., walrus, seals, etc.), caribou, birds, fish, and foraged foods.

8.2.2 Identifying, Assessing, and Synthesizing Evidence

A rigorous, systematic, and flexible approach was used to identify literature and evidence relevant to climate change, food systems, and health. The approach comprised three elements: building from previous assessments; conducting a comprehensive search of peer-reviewed and grey literature; and learning from public consultations and engagement.

This chapter built on international (IPCC, 2018; IPCC 2019a; IPCC, 2019b), national (Lemmen et al., 2008; Warren & Lemmen, 2014), and human health-specific assessments that summarized literature on the impacts of climate change on food-related health (Séguin, 2008; USGCRP, 2016). The chapter draws particularly on two chapters from the health-specific assessments *The Impacts of Climate Change on Water-, Food-, Vector- and Rodent-Borne Diseases* (Charron et al., 2008) and *Food Safety, Nutrition, and Distribution* (Ziska et al., 2016).

Literature published since the previous Canadian National Climate Change and Health Assessment in 2008 (Séguin, 2008) was identified and assessed using two separate literature searches, focusing on climate change impacts on food security and food safety in Canada. Five databases (PubMed, Web of Science, Scopus, Embase via Ovid, and MEDLINE via Ovid) were searched using search strings developed in consultation with a research librarian. The reference lists of all relevant literature were examined to identify articles not captured in the database search. Websites of key government and international agencies (e.g., provincial and territorial government websites, Public Health Agency of Canada, Health Canada, Canadian Food Inspection Agency, Food and Agriculture Organization of the United Nations, World Health Organization, US Centers for Disease Control and Prevention, World Food Programme) were examined to identify relevant grey literature. No language restrictions were placed on either search. Citations identified through these searches went through two levels of screening conducted by two independent reviewers. First, the titles and abstracts were screened for relevance, then, the full texts of articles were screened for relevance. Literature that discussed food security and/or food safety in the context of human health and climate change was included in this assessment. While Canadian research was prioritized, international research with results relevant to the Canadian context was also included.

The existing literature on climate change impacts on Indigenous food security primarily focuses on Inuit and First Nations peoples, with very limited Métis-specific literature (Halseth, 2015; Beaudin-Reimer, 2020). Wherever possible, specific Indigenous Peoples are distinguished in this chapter to reflect the diverse perspectives and experiences among First Nations, Inuit, and Métis peoples and communities. However, some generalizations are made, depending on the number and nature of citations used (e.g., Indigenous Peoples reflect more than one Indigenous group being referenced) and in instances where there may be shared experiences.

8.3 Climate Change Impacts on Food Systems in Canada

Globalization has created a global food system, in which Canada participates by exporting and importing raw and prepared food products to and from other regions of the world (Lake et al., 2012; O'Riordan & Lenton, 2013). Within Canada, regional and local food systems also co-exist and operate within smaller geographic boundaries. For example, Northern Indigenous food systems are often smaller in scale and rely largely on local foods sourced through hunting, trapping, fishing, gathering, and harvesting. Beyond food-generating practices, Indigenous food systems also encompass environmental governance and stewardship and involve the production, innovation, and transfer of Indigenous knowledge to maintain land-based practices (Delormier et al., 2017).

Relationships among food system components and human health in the context of climate change are dynamic and complex, in part due to the bi-directional relationship between climate change and food systems (Porter et al., 2014). While climate affects all components of the food system, food systems, in turn, can be a significant source of greenhouse gas (GHG) emissions and, thus, a driver of climate change (Fanzo et al., 2018; Friel, 2019). It is estimated that 21% to 37% of total global GHG emissions originate from food systems (Mbow et al., 2019).

Climate creates a number of challenges for food systems in Canada (Table 8.2), and these impacts are expected to increase as the climate warms. While Table 8.2 captures many examples, including some specific to Indigenous food systems, there are unique characteristics and challenges associated with various food systems throughout Canada that will mediate the impacts associated with climate change.

Table 8.2 Pathways through which climate change increases risks to food systems

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
Food production
• Increasing temperature extremes and variability, changes in precipitation patterns, and extreme weather events can damage crops, reduce agricultural productivity, and decrease yield (Easterling et al., 2007; Gornall et al., 2010; Butler, 2014b; Campbell et al., 2014; Fanzo et al., 2018; Dodd et al., 2018)
• The Canadian Prairies are projected to experience an increased risk of drought in the summer and fall, which can lead to reduced groundwater quality and quantity, and reduced water supply for irrigation of crops (Sauchyn et al., 2008; Sauchyn et al., 2020)
• Sea level rise can cause inundation of agricultural lands in coastal regions, damaging crops and creating unsuitable conditions for agricultural production. Inundation can also result in saltwater intrusion of aquifers, reducing the quality of irrigation water (Campbell et al., 2014)
• Increasing temperatures and changes in precipitation patterns may create more favourable conditions for pests, invasive species, and plant diseases (Gornall et al., 2010; Butler, 2014b; AAFC, 2015), increasing competition for resources and reducing crop productivity and quality
• Rising temperatures and increased concentrations of atmospheric CO_2 may decrease the effectiveness of some herbicides used for pest control (Porter et al., 2014)
• Increasing ozone pollution, a by-product of fossil fuel combustion, can inhibit photosynthesis, consequently reducing crop quality and productivity (Gornall et al., 2010; Butler, 2014b)
• Temperature extremes can adversely affect livestock health and decrease productivity (Butler, 2014b; Bishop-Williams et al., 2015)
• Extreme weather events may reduce land available for livestock pasture and foraging (AAFC, 2015)
• The distribution and productivity of natural and farmed fish will change as ocean and freshwater temperatures, and ocean acidification, increase (FAO, 2008; Campbell et al., 2014; Porter et al., 2014)
• Rising temperatures may create favourable conditions for aquatic diseases and invasive species (Rahel & Olden, 2008), reducing the quantity and quality of fish, shellfish, and other commercially and traditionally harvested marine animals (Larsen et al., 2014)

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
• Increasing temperatures and changing precipitation patterns are altering the quality and distribution of populations of traditionally harvested species in Canada (e.g., caribou) (CCA, 2014)
• Extreme weather events may facilitate chemical and bacterial contamination of food production sites (e.g., contaminated flood waters inundating agricultural crops) (Ziska et al., 2016)
• Increasing temperatures and changes in precipitation patterns may create favourable conditions for the growth and survival of toxigenic fungi and mycotoxin contamination of agricultural crops (Jaykus et al., 2008; Tirado et al., 2010)
• Climate change may create favorable conditions for pests, increasing the need for pesticides, which can lead to increased pesticide residues in the food supply (Lake et al., 2012)
• Increasing concentrations of atmospheric CO_2 can alter the nutritional content of some agricultural crops, decreasing concentrations of protein, iron, zinc, and other key minerals (Muncke et al., 2014; Porter et al., 2014; Ziska et al., 2016; Myers et al., 2017)
• In Northern Canada, climate change may allow for the emergence of new pathogens, viruses, and parasites that affect wildlife harvested as part of Indigenous traditional and country food systems (CCA, 2014)
• Decreasing ice thickness and coverage and water levels, as well as changing freeze-up and break-up periods, challenge the procurement of local foods for Northern Indigenous communities (Ford, 2008; Laidler et al., 2009; Wesche & Chan, 2010; Harper et al., 2015a; Wesche et al., 2016; Ford et al., 2019
Food processing
• Increasing temperatures and extreme heat events may increase the risk of food spoilage and/or contamination in processing facilities, which have food safety implications (Ziska et al., 2016)
• Traditional food storage, preservation, and preparation practices may be at risk; for example, permafrost thaw may affect the stability and safety of traditional in-ground freezers used by many Northern Indigenous communities (CCA, 2014)
• Reduced or variable availability of potable water may challenge food processing operations (Campbell et al., 2014)
• Extreme weather events (e.g., flooding) may disrupt energy supplies, labour availability, and processing facility infrastructure critical to processing operations (Ziska et al., 2016)

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
• Climate change impacts may affect the availability, quality, and cost of raw materials and inputs in the food production sector, from both international and domestic sources (Edwards et al., 2011; Wong & Schuchard, 2011)
Food distribution
• Temperature extremes, permafrost thaw, changes in precipitation patterns, changes in freeze–thaw cycles, and extreme weather events can cause physical damage and disruption to transportation infrastructure (Palko & Lemmen, 2017)
• Extreme weather events can damage distribution and storage facility infrastructure (e.g., grocery stores, food banks) (Biehl et al., 2018) and disrupt energy supplies, labour availability, and technological infrastructure critical for food distribution (Ziska et al., 2016; Biehl et al., 2018)
Food preparation and consumption
• Increasing temperatures may change food preparation behaviours (e.g., barbeques, picnics), increasing the risk of exposure to food-borne illness (Ziska et al., 2016; Levison et al., 2018)
• Increasing ocean temperature and changes in salinity increase the risk of pathogens in seafood, which is often consumed uncooked (e.g., oysters) (Jaykus et al., 2008; Tirado et al., 2010; Ziska et al., 2016)
Source: Adapted from Schnitter & Berry, 2019

8.4 Climate Change, Food Security, and Health in Canada

8.4.1 Food Security in Canada

The baseline level of food security contributes to the vulnerability of households to the food-related health impacts of climate change. Therefore, it is important to understand the baseline prevalence, distribution, determinants, and magnitude of food security in Canada. Approximately 12.7% of Canadian households experience some level of household food insecurity (Tarasuk & Mitchell, 2020). This prevalence is likely an underestimate, as the survey does not capture those living in First Nations communities (on-reserve), full-time members of the Canadian Forces, individuals in prisons, those living in some remote Northern communities, or individuals who are under-housed or homeless (Jessiman-Perreault & McIntyre, 2017).

Inequities exist with respect to how food security is distributed and experienced across Canada. Such inequities contribute to ongoing health disparities across the country (see Chapter 9: Climate Change and Health Equity). Household food insecurity is most prevalent in the territories and the Maritime provinces (Figure 8.2), and urban households experience food insecurity to a slightly greater degree (13%) than rural households (11%) (Tarasuk et al., 2016; Tarasuk & Mitchell, 2020). Household food insecurity is more common in households with children and those with lone parents, with lone female-headed households being most vulnerable (Tarasuk & Mitchell, 2020). The likelihood of severe food insecurity increases with decreasing household income (Statistics Canada, 2012). In 2017–2018, approximately 60% of Canadian households whose primary income source was social assistance reported experiencing food insecurity (Tarasuk & Mitchell, 2020). Household food insecurity is significantly higher among households where the respondent identified as Indigenous (28.2%) or Black (28.9%) (Tarasuk & Mitchell, 2020). Unemployment, lower education (less than a high school diploma), recent immigration (within five years), and self-identification as 2SLGBTQQIA+ (two-spirit, lesbian, gay, bisexual, transgender, queer, questioning, intersex and asexual) also increase the risk of household food insecurity (PHAC, 2018).

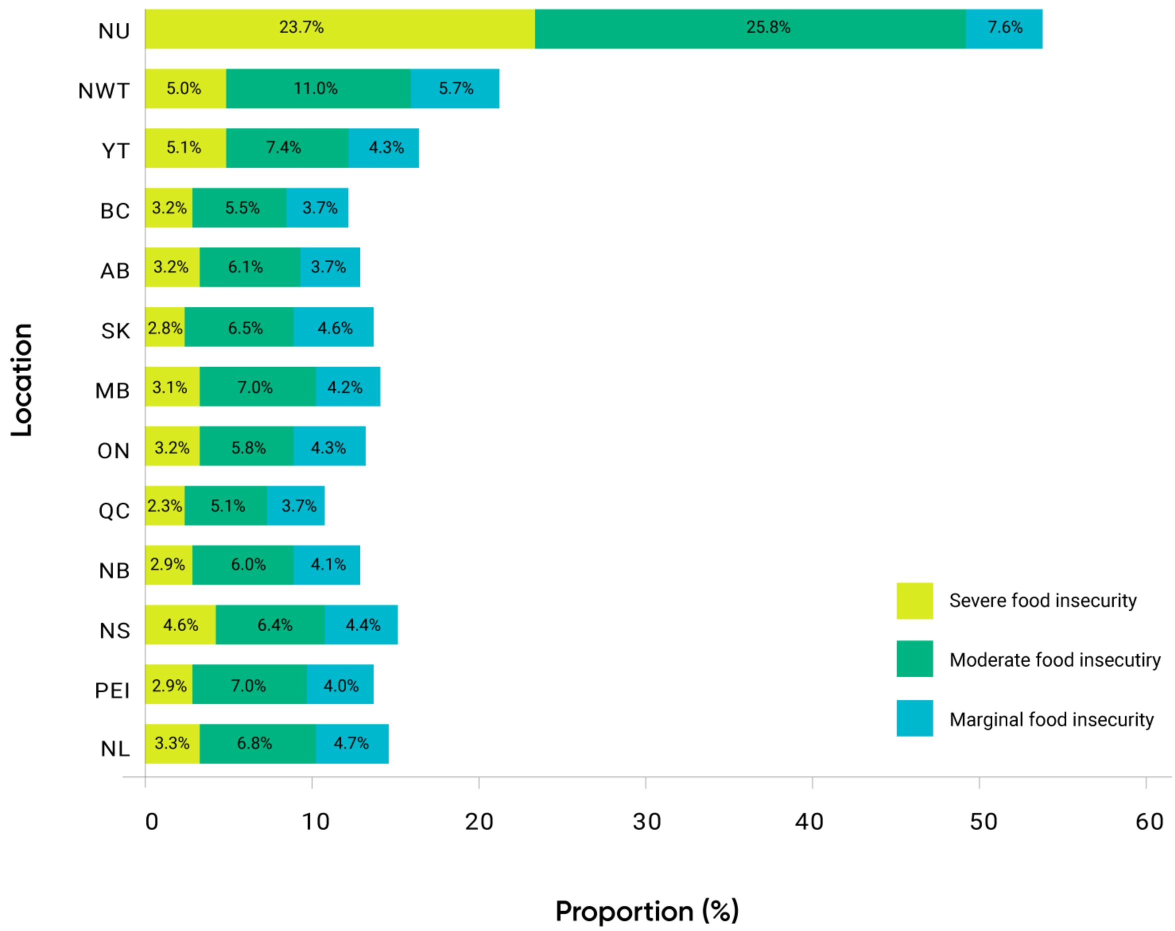


Figure 8.2 Baseline household food insecurity status in Canada by province and territory, which can underpin vulnerability to food-related climate change impacts on health. Source: Adapted from Tarasuk & Mitchell, 2020; data from Statistics Canada, 2018.

Indigenous households, in remote and Northern communities in particular, are often significantly challenged by food insecurity, which is often rooted in ongoing colonial legacies (Box 8.1). Indeed, the prevalence of food insecurity is 3.7 times higher among Inuit adults, 2.7 times higher among First Nations adults (living off reserve), and 2.2 times higher among Métis adults than among non-Indigenous adults (PHAC, 2018) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). On-reserve data indicates that just over half (50.8%) of First Nations adults live in food insecure households, and 43.2% of households with children were classified as food insecure (FNIGC, 2018). With over 68% of households experiencing some level of food insecurity (Rosol et al., 2011; Huet et al., 2012; Fillion et al., 2014), Inuit living in Nunavut have a higher prevalence of food insecurity than any other Indigenous Peoples living in a high-income country (CCA, 2014).

Box 8.1 Food colonization increases climate change vulnerability for Indigenous Peoples

Indigenous food systems are particularly vulnerable to climate change. The existing higher prevalence of food insecurity for many Indigenous Peoples contributes to climate change vulnerability, which is often rooted in ongoing colonial legacies. Indeed, Indigenous Peoples in Canada score far worse on virtually every health indicator than the general public, a situation that has been directly attributed to historical and ongoing processes of colonization (Delormier et al., 2017; Greenwood et al., 2018). Food colonization is a unique food security concern for Indigenous Peoples (Cidro et al., 2018) and has played a leading role in the disruption and undermining of Indigenous food systems (Morrison, 2011; Whyte, 2016).

Colonization has resulted in the widespread loss of connection and access to the lands that supported Indigenous food systems (e.g., through hunting, gathering, fishing, cultivation, and trading) (Desmarais & Wittman, 2014). Colonization and the resulting disruption of Indigenous food systems were by and large intentional, paving the way for an imposed food system that has contributed to the health disparities experienced by Indigenous Peoples in Canada, including higher rates of food insecurity and chronic diseases (Desmarais & Wittman, 2014; Grey & Patel, 2015). In the Indigenous food security movement, underlying structures of this ongoing colonialism are identified as the most critical determinant of poor health outcomes (Martens et al., 2016). The decrease in consumption of healthy land-based foods, such as wild meats, fish, plants, and berries, due to environmental displacement, dispossession, restrictive policies, and cultural change, is a direct result of this process (Rudolph & McLachlan, 2013; Delormier et al., 2017). Food insecurity, primarily with respect to traditional foods, has resulted in loss of Indigenous knowledge and, in turn, has affected the nutritional, emotional, and spiritual health of Indigenous Peoples in Canada.

Studies have shown that Indigenous food systems are central to Indigenous health and well-being (Desmarais & Wittman, 2014) and that increased intake of traditional foods improves Indigenous Peoples' diet quality and health (Johnson-Down & Egeland, 2010; Gagné et al., 2012; Batal et al., 2017). Traditional foods contribute to health and well-being because of their frequently higher nutritional value, the sense of identity acquired through their traditional harvesting, preparation, and sharing practices, and the increased levels of physical activity needed for their procurement (Harper et al., 2015a; Batal et al., 2017). For instance, studies conducted with the Gwich'in people in British Columbia (Kermoal & Altamirano-Jiménez, 2016) and in the Northwest Territories (Parlee et al., 2005) found that berry picking connects women to their spiritual, emotional, mental, and physical selves, in addition to providing significant nutritional value.

Women, youth, and children are identified as particularly vulnerable to the impacts related to loss of access and control over traditional lands that support Indigenous food systems (Lemke & Delormier, 2017; Neufeld et al., 2020). The Indigenous knowledge that has been passed on in support of identity, language, and purpose has been disrupted at an intergenerational level (Delormier et al., 2017; Lemke & Delormier, 2017). Rudolph & McLachlan (2013) maintain that "food insecurity and diet-related disease within Indigenous communities are thus best understood in the context of historical injustice." Taken together, and considering the important role that Indigenous food systems play in Indigenous Peoples' health and well-being, climate change impacts on Indigenous food systems have wide-ranging impacts on Indigenous Peoples, Indigenous knowledge systems, and Indigenous Rights.

While some individual and household characteristics are associated with food insecurity trends (e.g., socio-economic status, household living arrangement, Indigenous identity), it is important to note that population groups are not homogeneous and that food security status is not static. Each individual uniquely experiences a range of intersecting social, political, economic, and environmental factors that contribute to differential food security status over time (Kapilashrami & Hankivsky, 2018), and therefore different and changing vulnerability to climate change impacts on food systems. In some cases, these factors may intersect in ways that compound vulnerability to food insecurity in the context of climate change, creating disproportionate impacts on some population groups. Food insecurity has close linkages to other indicators of material and social disadvantage (Tarasuk & Mitchell, 2020). In many cases, disadvantage can further enhance vulnerability to climate-related health risks by creating difficulties that hinder individuals from taking measures to protect themselves and adapt (see Chapter 9: Climate Change and Health Equity).

8.4.2 Food Security as a Public Health Issue

Food security is an important public health challenge that will be affected, mediated, and modified by climate change. Household food insecurity is associated with many adverse physical and mental health outcomes, including nutritional deficiencies, cardiovascular disease, diabetes, oral health issues, and depression (Table 8.3) (McLeod & Veall, 2006; Muldoon et al., 2013; Tarasuk et al., 2016; Jessiman-Perreault & McIntyre, 2017). Malnutrition due to food insecurity can increase the body's susceptibility to disease, which can, in turn, limit an individual's ability to access and use food. This can further exacerbate food insecurity and malnutrition and establish a vicious cycle of food insecurity and poor health (Aberman & Tirado, 2014). Furthermore, one study in Ontario demonstrated that food insecurity can indirectly stress the health care system, as adults experiencing food insecurity require more health care services and are more likely to become high-cost health care users compared to adults who are food secure (Figure 8.3) (Tarasuk et al., 2015; Li et al., 2016; Tarasuk et al., 2016). Given these implications for the health sector, food security in a changing climate is an important public health challenge.

Table 8.3 Examples of health and social challenges associated with food insecurity that could be exacerbated by climate change

CATEGORY	HEALTH AND SOCIAL CHALLENGES
Maternal health and birth outcomes	• Inadequate nutrition during pregnancy can have negative health impacts on both the mother and child. • Maternal food insecurity is associated with an increased risk of birth defects. • Household food insecurity can adversely affect infant and young child feeding behaviours and limit the sustainability of breastfeeding.
Child development	• Food insecurity can impede both physical and cognitive growth and development in early life. • Food insecurity is associated with poorer general health in children. • Food insecurity is associated with iron deficiency anemia and has been linked to the development of a variety of chronic conditions, including asthma and depression.
Health status and chronic disease	• People who are food insecure are more likely to experience a myriad of chronic conditions, including both mental and physical health challenges. • Food insecure individuals self-report higher levels of poorer health, type 2 diabetes, heart disease, high blood pressure, and food allergies. • Food insecurity poses additional barriers to chronic disease management, which increases the likelihood of adverse outcomes.
Mental health and emotional well-being	• Food insecurity affects social and mental well-being, which can increase the likelihood of depression, distress, and social isolation (see Chapter 4: Mental Health and Well-Being). • Child hunger has been identified as a risk factor for depression and suicidal symptoms in adolescence and early adulthood.
Health care costs	• Food insecurity leads to increased health care costs and increases the probability that adults will become high-cost health care users. • In Ontario, total annual health care costs were 23%, 49%, and 121% higher for adults in marginally, moderately, and severely food insecure households, respectively.

Source: Adapted from Li et al., 2016

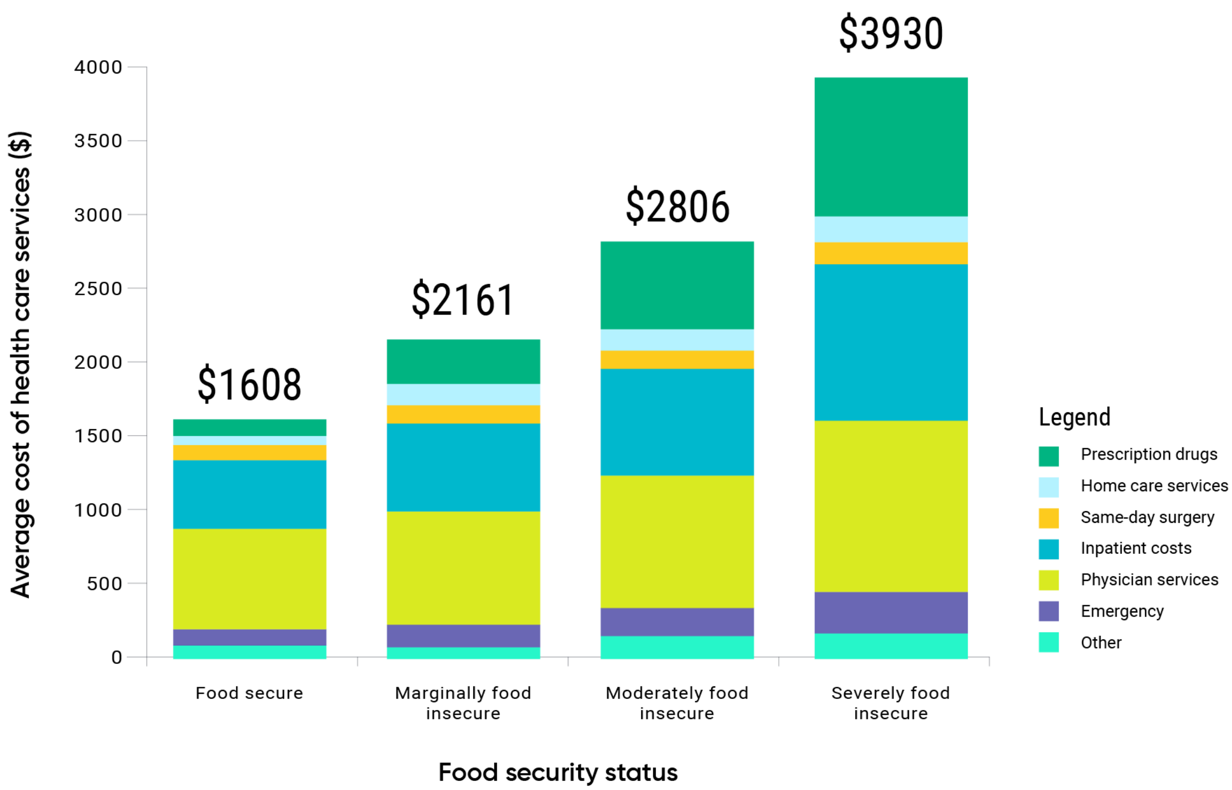


Figure 8.3 Average health care costs incurred over 12 months by Ontario adults (18 to 64 years of age), according to household food insecurity status. Source: Tarasuk et al., 2015.

8.4.3 Climate Change Impacts on the Pillars of Food Security

Climate change poses risks to food systems (see section 8.3 Climate Change Impacts on Food Systems in Canada) through complex interactions that influence the pillars of food security — availability, accessibility, utilization, and stability — which can lead to negative health outcomes among Canadians. Threats to these pillars are discussed below.

8.4.3.1 Climate Change Impacts on Food Availability

There are three primary elements associated with food availability: production, distribution, and exchange of food (Ericksen, 2008). Climate change can disrupt each of these elements (Figure 8.1). For example, crop yields are highly sensitive to changes in temperature and water availability. Air temperatures higher than 30°C are associated with reduced yields for rain-fed crops (Myers et al., 2017). Temperature variability and extremes can also damage crops, especially if these events occur during critical stages of crop development (Easterling et al., 2007; Gornall et al., 2010). In 2012, for example, following a summer of extreme heat and drought, fruit trees in Ontario bloomed earlier than seasonal norms. Temperatures then dropped, causing a frost event that resulted in an 80% loss of apple crops and a 50% loss of strawberry crops in Ontario (ECCC, 2017). It is projected that, in Eastern and Central Canada, there will be an increase in the frequency of winter bud kill and late killing-frost events (Campbell et al., 2014), which will negatively affect agricultural food production.

Canada is also expected to experience an increase in frequency and severity of extreme weather events (Bush & Lemmen, 2019), which can hinder agriculture and livestock production and also disrupt food distribution and exchange. For example, a powerful winter storm in January 2020 caused the City of St. John's, Newfoundland and Labrador, to declare a state of emergency, ordering all businesses, including grocery stores, to close. Grocery stores re-opened after four days; however, high consumer demand, combined with a disrupted regional food supply chain, resulted in many stores selling out of food and turning away customers who had been waiting for hours to purchase basic food staples (Roberts & Cooke, 2020).

Climate change is expected to affect the diversity of available food globally, which has important health implications. Springmann et al. (2016) determined that a total of 529,000 deaths worldwide (78 per million, base year: 2010) could occur between 2010 and 2050 due to climate-related reductions in food availability and changes in fruit, vegetable, and red meat consumption. In this model, climate-related changes in diet (i.e., decreased fruit and vegetable consumption) were projected to result in twice as many deaths as climate-related reductions in caloric intake. For Canada, the study projected that between 25 and 33 deaths per million will occur in 2050 due to climate-related changes in diet and weight, almost all of which are attributable to reductions in fruit and vegetable consumption (Springmann et al., 2016). Should Canada's population grow to a projected 44 million inhabitants (Statistics Canada, 2020), an additional 1100 to 1450 deaths might be expected in 2050. The adoption of GHG mitigation strategies could decrease the number of deaths worldwide due to climate-related changes in food availability in 2050 by 29% to 71%; however, excess deaths would remain even under negative emissions scenarios (Springmann et al., 2016).

8.4.3.2 Climate Change Impacts on Food Accessibility

Food accessibility relates to the affordability, allocation, and socio-cultural preferences for food (Figure 8.1) (Ericksen, 2008), and can be affected by climate change through indirect, but well-known, pathways. Several studies have projected the impact of climate change on world food prices (Easterling et al., 2007; Lake et al., 2012). For example, global models project that, under the Representative Concentration Pathway (RCP) 6.0 emission scenario, cereal prices will increase by 1% to 29% by 2050 (Mbow et al., 2019). Other staples, such as rice and sugar, are projected to increase in price by as much as 80% compared to their reference levels without climate change (Schmidhuber & Tubiello, 2007). Canada's Food Price Report identified climate change as a significant driver of food price increases since 2016. Climate change impacts, including changing weather patterns, droughts, wildfires, reduced access to fresh water, and rising sea levels, are projected to affect Canadian food systems and contribute to a 3% to 5% increase in overall food prices in 2021 (Charlebois et al., 2020; Charlebois et al., 2021).

As food prices rise, households may lack the economic means to purchase adequate, healthy, and preferred foods. Indeed, increased food prices can force consumers, especially those living on low incomes who are already at risk of food insecurity, to purchase lower-cost energy-dense processed foods, which contribute to excess sodium, sugar, and saturated fat intake and may have negative nutrition and health consequences (Lock et al., 2009; Lake et al., 2012). Substituting nutritious foods with inexpensive energy-dense processed foods can lead to an increased incidence of nutrient deficiencies and non-communicable diseases, such as obesity and type 2 diabetes (Gibson et al., 2004; Lake et al., 2012; Marushka et al., 2017; Kenny et al., 2018).

Food accessibility is also a function of physical access to food, which can be affected by climate change and extreme weather events, in particular (Palko & Lemmen, 2017). For instance, high winds, extreme precipitation, flooding, and extreme heat events can disrupt public transportation systems, which many urban dwellers rely on to access retail food distribution sites (Palko & Lemmen, 2017). These effects may be particularly pronounced for those with disabilities and those living in neighbourhoods categorized as "food deserts," where households are primarily relying on a low income and have little or no nearby access to stores or restaurants that provide healthy and affordable foods (Biehl et al., 2018).

8.4.3.3 Climate Change Impacts on Food Utilization

Food security extends beyond the supply and demand dynamics of markets to the use of food (Figure 8.1), including important aspects related to food safety (see section 8.5 Climate Change Impacts on Food Safety in Canada) and the nutritional and socio-cultural value of food (see section 8.4.3.3.1 Climate Change Impacts on Nutrient Availability) (Ericksen, 2008; Myers et al., 2017).

Climate change will influence the nutritional value and nutrient composition of diets through its influence on the pillars of food security, as well as its impact on the conditions under which food is produced, distributed, and individually chosen (The Royal Society, 2009; Lake et al., 2012). As discussed below, such changes have implications for overall human health and nutrition through possible effects on nutrient availability, biodiversity-related impacts on nutrient access, and dietary transitions and substitutions.

8.4.3.3.1 Climate Change Impacts on Nutrient Availability

Globally, increasing carbon dioxide (CO_2) concentrations associated with climate change are projected to alter the nutrient content and density of agricultural and seafood products, which can affect food security (Macdiarmid & Whybrow, 2019). Experiments growing crops (e.g., wheat, rice, legumes) in controlled environments have found that zinc, iron, and protein concentrations are reduced by 3% to 15% when grown in conditions with elevated CO_2 (550 to 690 ppm) (Myers et al., 2014; Myers et al., 2017). Phytate content was also reduced, which could offset some of the zinc and iron losses, as phytates typically reduce micronutrient bioavailability (Myers et al., 2014; Myers et al., 2017). Nevertheless, when these nutrient changes are applied to contemporary diets globally, it is projected that hundreds of millions of people will be placed at risk of zinc, iron, and/or protein deficiencies, and the existing deficiencies of an estimated two billion people will be exacerbated (Myers et al., 2017).

Increasing CO_2 concentrations are also changing the nutritional value of important forage for pollinator species (Myers et al., 2017). Although the net effect of climate change on pollinators remains unclear, studies indicate that a reduction in animal pollination would decrease yields of numerous pollinator-dependent food crops that provide important macro- and micronutrients to humans (Myers et al., 2017). Pollinator declines over the long term could reduce dietary intake of fruits, vegetables, nuts, and seeds in many countries, leading to increased child mortality and birth defects from vitamins A, E, and B6 (folate) deficiencies, and increased risks of heart disease, stroke, type 2 diabetes, and certain cancers (Myers et al., 2017). Varying soils and growing conditions, as well as methods of harvesting, processing, and storing food crops, can also influence nutrient composition. For example, selenium content varies by geography according to the soil mineral content (Lake et al., 2012).

The health impacts of reduced nutrient densities on food security, however, will depend on overall dietary diversity, as well as country-specific enrichment and fortification policies (CFIA, 2014). Similar to impacts in other higher-income countries, the impact will likely be lower in Canada, where many staple foods, including wheat flour, are fortified with essential micronutrients such as iron and folic acid (CFIA, 2014). Nevertheless, health impacts may be more pronounced in specific regions of Canada, such as Northern communities, where challenges accessing a diverse diet including fruits, vegetables, and whole grains already exist. Further research is therefore needed to understand how climate-related changes in nutrient availability will affect food security in Canada.

8.4.3.3.2 Impacts of Climate-Related Biodiversity Loss on Nutrient Access

The impacts of climate change on biodiversity loss will increase risks to food and nutrient access (Rose et al., 2001; Romero-Lankao et al., 2014). Biodiversity reflects the number and variety of living organisms and plays a key role in boosting ecosystem productivity, resilience, and sustainability — in turn, offering many benefits to humans and animals, such as soil formation and retention, pollination, climate regulation, and resources for foods and pharmaceuticals (IPBES, 2018).

While agriculture products provide the majority of dietary energy (i.e., calories), seafood is an important source of nutrients, such as protein, fat, minerals, and vitamins, for many populations, including Canadians (Myers et al., 2017; Marushka et al., 2019). Global estimates suggest that climate-related declining fish harvests (IPCC, 2019a) will leave 845 million people vulnerable to deficiencies in iron, zinc, and vitamin A, and 1.4 billion people vulnerable to deficiencies of vitamin B12 and omega-3 long-chain polyunsaturated fatty acids by 2050 (Golden et al., 2016). Those who are in low-resource settings will be at greater risk of nutrient deficiencies because of their limited access to alternatives, such as other sources of animal protein, supplements, and nutritionally fortified or enriched foods (Myers et al., 2017).

The impacts of biodiversity loss are inequitably distributed among human populations. In Canada, Indigenous Peoples who depend on the land for sustenance are particularly vulnerable to climate-related biodiversity loss (Rose et al., 2001; Richmond & Ross, 2009; Anderson et al., 2018; Kenny et al., 2018; Boulanger-Lapointe et al., 2019). For instance, drawing on observations of declining food species in 36 Indigenous communities spanning Nunavut, the Inuvialuit Settlement Region, and Nunatsiavut, Rosol et al. (2016) explored the likely nutritional impact of possible future diet substitutions. In some cases, substitutions resulted in similar nutrient intake, while other alternatives were of lower nutritional value. For example, if Inuit in the region of Kivalliq replaced 50% of their fish intake with duck (gram-for-gram), vitamin D intake would decrease by 94%, while iron and zinc intake would both increase (Rosol et al., 2016). Similarly, the diets of several First Nations in British Columbia rely on locally harvested seafood, meaning that their nutritional health is highly vulnerable to potential climate-related declines in seafood abundance (Box 8.2) (Rosol et al., 2016; Marushka et al., 2017; Watts et al., 2017; Rapinski et al., 2018). Indigenous Peoples may respond to these changes by purchasing more retail food; however, this response may increase health risks, as shifts from locally harvested to retail food often result in increased consumption of processed foods that are higher in fat, refined sugar, and sodium (Marushka et al., 2019). Furthermore, in many remote Indigenous communities, retail foods are expensive and limited in quantity, quality, and diversity — and do not support cultural continuity, which is a critical determinant of Indigenous Peoples' health — thus complicating effective options for adaptation response (Marushka et al., 2019). Along with the effects on diet quality, these declines in locally harvested food also have detrimental impacts on mental health outcomes, cultural practices, language, self-determination, and social cohesion (Batal et al., 2017; Marushka et al., 2019) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 4: Mental Health and Well-Being).

Box 8.2 Climate change impacts on marine environments among coastal First Nations communities in British Columbia

Locally harvested seafood is a critical component of the diet and health of coastal First Nations within British Columbia. Climate change is projected to exacerbate existing stressors (e.g., colonial fisheries regulations, environmental degradation, socio-economic inequalities) on the access to and quality of this Indigenous food system, which has implications for the health and nutrition of First Nations Peoples in this region (Marushka et al., 2019).

For instance, one study estimated that traditional seafood consumption provided coastal First Nations with the daily Dietary Reference Intake recommendations of omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (74% to 184%) and vitamin B12 (84% to 152%), and substantial levels of niacin (28% to 55%), selenium (29% to 55%), vitamin D (15% to 30%), and protein (14% to 30%). By 2050, climate change projections for these coastal communities are projected to reduce the intake of essential nutrients by 21% under a "strong mitigation" (RCP2.6) scenario and 31% under a "business-as-usual" (RCP8.5) climate change emission scenario (Marushka et al., 2019). The relative impact of these changes varied among sex and age groups, based on their average seafood consumption (Marushka et al., 2019). Analysis suggested that substituting chicken, canned tuna, and bread would not replace the nutrients lost due to climate-related seafood declines, suggesting that market foods cannot easily replace the nutritional value of traditional foods (Marushka et al., 2019).

In an effort to promote food security and sovereignty (Box 8.1), strategies to adapt to climate change adaptation that improve seafood harvest potential and access rights to coastal First Nations communities are critical (Box 8.6). In response to the need for Indigenous self-determined adaptation (Section 8.6), the First Nations Health Authority, under Health Canada's HealthADAPT program, is establishing the WATCH: We All Take Care of the Harvest (Safe and Secure Harvesting of Marine Foods in the Context of Climate Change) program, which will result in the development of local- and Indigenous-relevant adaptation strategies to reduce the impacts of climate change on Indigenous marine food systems and enhance the resilience of First Nations communities in British Columbia (Health Canada, 2019).

8.4.3.3.3 Impacts of Dietary Transitions and Substitutions on Nutrient Use

Climate change can exacerbate existing and emerging nutritional stresses, including the current nutrition transition affecting populations in and outside of Canada. The nutrition transition, which is linked to globalization and urbanization, is a shift from traditional diets toward foods higher in calories, fats, and sugars, accompanied by a rise in sedentary lifestyles (Wheeler & Von Braun, 2013; Breewood, 2018). A diet high in energy-dense processed foods rich in calories, salt, sugar, and saturated fat, and low in whole grains, nuts, seeds, legumes, fruits, and vegetables, is a leading risk factor for death and disability in Canada (IHME, 2016; Bacon et al., 2019).

Globally, the nutrition transition is contributing to a dual burden of overnutrition (e.g., obesity) and undernutrition, along with increased risks of non-communicable and infectious disease (FAO et al., 2018). Some of these health effects may be more pronounced for specific population subgroups. Monitoring of, and support for, populations that are disproportionately affected is needed, particularly for lower-income households that are most affected by rising food prices; those already at nutritional risk, such as women, children, and seniors; and those in remote geographical areas, including many Indigenous Peoples (Ford & Beaumier, 2011; Lake et al., 2012; Bunce et al., 2016; Collings et al., 2016). More research is also needed on the nature, extent, and magnitude of climate change impacts on the nutrition transition.

8.4.3.4 Climate Change Impacts on Food Stability

Longer-term food security requires that food be available, accessible, and used by people in a sustained and stable manner over time (FAO, 2008). Climate change can decrease the stability of food systems, which has a direct impact on all pillars of food security (Figure 8.1). For example, climate change increases the spatial and temporal variability in food production patterns, which affects food availability. Food prices may also fluctuate to a greater degree, which will have implications for accessibility. Many knowledge gaps exist in terms of how climate change will influence the volatility and stability of global food systems and food security, especially with respect to food access and use (Myers et al., 2017).

8.5 Climate Change Impacts on Food Safety in Canada

8.5.1 Climate Change, Food Safety, and Food-Borne Pathogens

Food safety can be compromised at any point along food system pathways (Figure 8.1). Given the estimated four million cases of food-borne illness per year, microbial food safety is an important public health concern in Canada (Thomas et al., 2013). Food-borne illnesses are acquired through the ingestion of contaminated food, and symptoms can range from diarrhea and vomiting to more severe illness (e.g., Guillain-Barré syndrome, hemolytic uremic syndrome) and death. In Canada, five pathogens (norovirus, *Clostridium perfringens*, *Campylobacter* spp., *Salmonella* spp., and *Bacillus cereus*) account for over 90% of food-borne illnesses for which the causative agent is known (Table 8.5) (Thomas et al., 2013). At least four of these pathogens are known to be climate sensitive (Kovats et al., 2004; Fleury et al., 2006; Lake et al., 2009; Valcour et al., 2016; Wu et al., 2016; Lake, 2017; Park et al., 2018).

Indeed, in many cases, climatic conditions are directly linked to food-borne illness, as pathogen occurrence in foods is affected in the short and long term by climate variables, including temperature, precipitation, extreme weather events, and ocean warming and acidification (Semenza et al., 2012a; Liu et al., 2013; Hellberg & Chu, 2015; Lake, 2017; Lake & Barker, 2018). Increasing temperature and extreme weather events rank in the top three of 19 economic, environmental, and social factors influencing food safety in Canada (Charlebois & Summan, 2015). The precise magnitude of climate change impacts on the burden of food-borne disease in Canada is uncertain, due to a paucity of research; however, given that many food-borne pathogens are climate sensitive (Lake et al., 2009; Tirado et al., 2010; Semenza et al., 2012a; Semenza et al., 2012b; Liu et al., 2013; Hellberg & Chu, 2015; Wu et al., 2016; Lake, 2017; Lake & Barker, 2018), the overall food-borne disease burden both current and emerging (previously rare) pathogens is expected to increase. For instance, mathematical models suggest that climate change will increase the burden of specific pathogens in food in Canada (e.g., *V. parahaemolyticus* in oysters) (Smith et al., 2015) (Box 8.4).

Table 8.4 Climate change impacts on the occurrence of food-borne pathogens and the current annual cases per 100,000 in Canada

PATHOGEN	SYMPTOMS[a]	ANNUAL CASES PER 100,000 (2006)[b]	CLIMATE INFLUENCE ON PATHOGEN OCCURRENCE[c]
Norovirus	Nausea, vomiting, diarrhea, stomach cramps, low-grade fever, chills, headache, muscle aches, fatigue	3,223.79	Decreased air temperature, extreme weather events (e.g., heavy precipitation, flooding)
Clostridium perfringens	Diarrhea, pain and cramps, stomach bloating, increased gas, nausea, weight loss, loss of appetite, muscle aches, fatigue. In rare cases, severe dehydration, hospitalization, death	544.50	Uncertain, but might thrive in drought conditions
Campylobacter spp.	Fever, nausea, vomiting, stomach pain, diarrhea. In rare cases, hospitalization, long-lasting health effects, death	447.23	Changes in the timing or length of seasons, increased air temperature, precipitation, flooding
Salmonella spp., non-typhoidal	Chills, fever, nausea, diarrhea, vomiting, stomach cramps, headache. In rare cases, hospitalization, long-lasting health effects, death	269.26	Changes in the timing or length of seasons, extreme weather events, increased air temperature
Bacillus cereus	Diarrhea, vomiting. In rare cases, hospitalization, long-lasting health effects, death	111.60	Changes in the timing or length of seasons, drought
Verotoxigenic *Escherichia coli* non-O157	Diarrhea. In rare cases, hospitalization, long-lasting health effects, death	63.15	Changes in the timing or length of seasons, extreme weather events, increased air temperature

PATHOGEN	SYMPTOMS[a]	ANNUAL CASES PER 100,000 (2006)[b]	CLIMATE INFLUENCE ON PATHOGEN OCCURRENCE[c]
Verotoxigenic *Escherichia coli* O157	Diarrhea. In rare cases, hospitalization, long-lasting health effects, death	39.47	Changes in the timing or length of seasons, extreme weather events, increased air temperature
Toxoplasma gondii	Minimal to mild illness with fever. In rare cases, inflammation of the brain, infection of other organs, birth defects	28.10	Extreme weather events, increased air temperature
V. parahaemolyticus	Diarrhea, stomach cramps, nausea, vomiting, fever, headache. In rare cases, liver disease	5.53	Extreme weather events, increased air temperature, increased sea surface temperature
Listeria monocytogenes	Fever, nausea, cramps, diarrhea, vomiting, headache, constipation, muscle aches. In severe cases, stiff neck, confusion, headache, loss of balance, miscarriage, stillbirth, premature delivery, meningitis, death	0.55	Extreme weather events, increased air temperatures, precipitation
Vibrio vulnificus	Diarrhea, stomach cramps, nausea, vomiting, fever, and headache. In rare cases, liver disease	< 0.01	Extreme weather events, increased air temperatures, increased sea surface temperature

a. Government of Canada, 2019.

b. Thomas et al., 2013.

c. Hellberg & Chu, 2015; Yan et al., 2016; Ziska et al., 2016.

Source: Smith & Fazil, 2019

The relationship between climate change and food-borne illness can be estimated using short-term seasonal trends as a proxy. Many studies in temperate regions similar to Canada have linked food-borne contamination and disease incidence with seasonal trends (Semenza et al., 2012a; Semenza et al., 2012c). A review analyzing studies of food-borne illness in temperate countries identified consistent summer peaks for disease caused by *Campylobacter* spp., *Salmonella* spp., verotoxigenic *Escherichia coli* infection, *Cryptosporidium* (bi-modal peak with spring and summer highs), and giardiasis (Lal et al., 2012). In New Brunswick, the incidence of Campylobacter, *E. coli*, *Giardia*, and *Salmonella* infections were greater in the spring and/or summer months (Valcour et al., 2016). In Alberta and Newfoundland and Labrador, ambient air temperatures were positively associated with *Campylobacter* spp., pathogenic *E. coli*, and *Salmonella* spp. infections (Fleury et al., 2006). Non-cholera Vibrio spp. infections have been associated with rising air and water temperatures and prolonged summer seasons (Semenza, et al., 2012a; Semenza et al., 2012c). Recently, it has been proposed that non-cholera Vibrio spp. can act as an indicator of climate change in marine systems due to their climate sensitivity (Baker-Austin et al., 2017).

Risks of climate-related food-borne illness are expected to vary across Canada, due in part to regional and local consumption preferences; for example, risks from seafood-associated pathogens will likely be greater in regions with high seafood consumption (e.g., coastal regions). Inuit are at increased risk of climate-related impacts on food safety, due in part to climate-sensitive traditional food practices, such as the consumption of raw meats, which are sensitive to even slight changes in food storage and transport temperatures (Pardhan-Ali et al., 2012a; King & Furgal, 2014; Harper et al., 2015a; Harper et al., 2015b; Jung & Skinner, 2017; Rapinski et al., 2018; Harper et al., 2019). Furthermore, climate change may introduce new microbial contamination into Northern regions through changes to wildlife ranges (Jenkins et al., 2013), permafrost thaw, and other environmental changes (Harper et al., 2015a). Additional research is needed on climate-related food safety risks that are unique to First Nations, Inuit, and Métis peoples, as well as Northern communities (Hedlund et al., 2014).

8.5.1.1 Food System Pathways Through Which Climate Change Affects Food Safety

Climate change affects the growth, survival, abundance, and range of pathogens throughout food systems, including during food production, processing, distribution, preparation, and consumption (Semenza et al., 2012a; Semenza et al., 2012c). An overview of how climate change can affect microbial food safety at each step of food systems, using *E. coli* in lettuce as an example, is provided in Box 8.3.

Box 8.3 Climate change impacts throughout food systems can increase public health risks: *Escherichia coli* O157 in lettuce as an example of a climate-sensitive food-borne pathogen

E. coli O157 is a zoonotic enteric pathogen that colonizes the gut of domestic livestock, such as cattle, and subsequently is shed in feces. Across North America, this pathogen has been implicated in an increasing number of outbreaks associated with produce, including fruits, leafy vegetables, and sprouts (Rangel et al., 2005; Heiman et al., 2015; Coulombe et al., 2020). Lettuce is the most common produce commodity associated with *E. coli* O157 outbreaks (Heiman et al., 2015).

Figure 8.4 presents a conceptual model of how climate change can increase lettuce contamination, thus creating public health risks. Lettuce can be exposed to *E. coli* through the transfer of contaminated feces or manure through air, groundwater, soil, and surface water reservoirs. Climate and weather variables, such as the timing and intensity of precipitation and temperature changes, can affect the level and prevalence of *E. coli* O157 throughout the production period through to harvest (Table 8.6). This, along with human handling and consumption practices, has a direct impact on the public health burden of infections with *E. coli* O157.

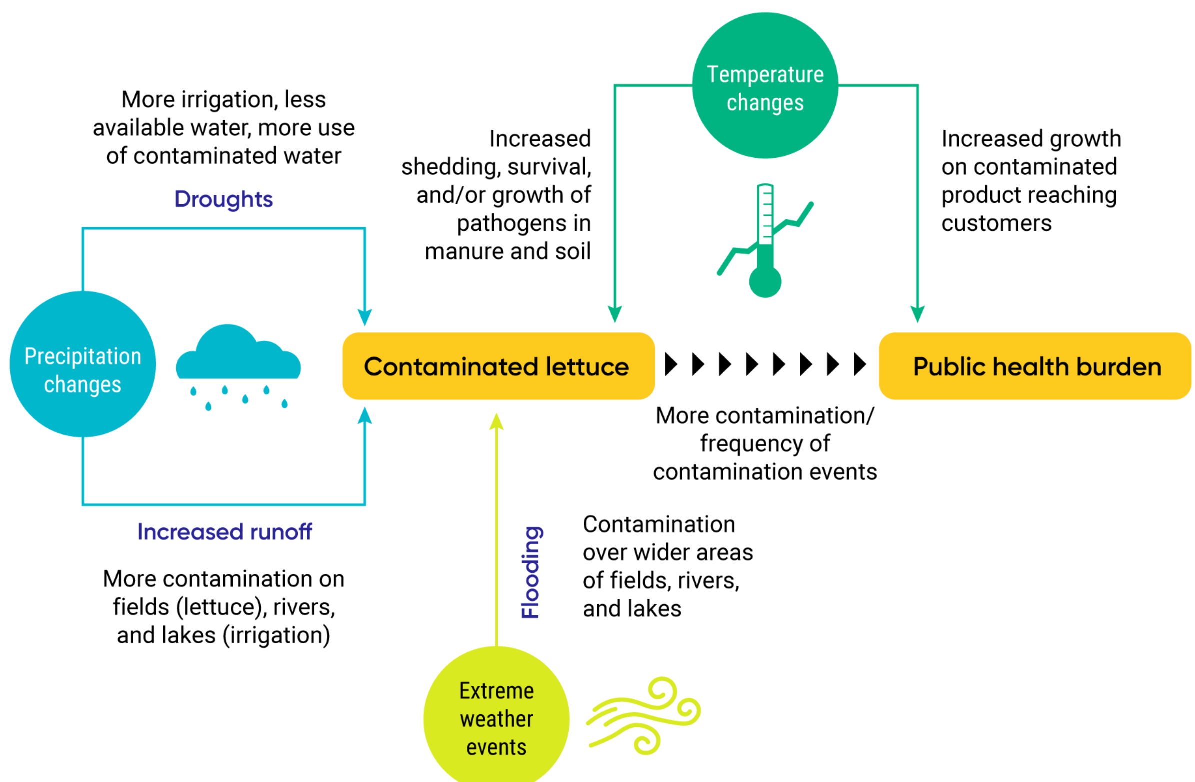


Figure 8.4 Climate-related contamination pathways of lettuce grown in Canada from pathogens shed from livestock.

Table 8.5 Selected components of lettuce contamination pathways that are affected by climate change

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Shedding of pathogens by livestock	Conflicting evidence that shedding rates and amounts are influenced by air temperature and heat stress	Not applicable	Not applicable	Not applicable
Pathogen persistence in feces and manure	Growth and death rates are influenced by temperature	Not applicable	Heavy rain can leach or wash pathogens from feces and manure into the environment, including soil that might be used to grow lettuce	Persistence and growth are favoured by high RH
Pathogen occurrence and persistence in soil	Growth and death rates are influenced by temperature	Not applicable	Longer elapsed time between manure application and rain is associated with less leaching; heavy rain can leach or wash pathogens from soil into the environment; amount of rainfall dictates frequency of irrigation with potentially contaminated water that is applied to lettuce; precipitation can result in wet deposition of airborne pathogens	Persistence and growth are favoured by high RH
Pathogen occurrence in groundwater	Not applicable	Not applicable	Heavy rain can leach pathogens into groundwater, which then might be used for irrigation, processing, etc.	Not applicable

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Pathogen occurrence and persistence in surface water	Higher temperatures can drive more cattle to surface water and increase direct deposition	Persistence in water bodies may be influenced by surface temperature	Increased precipitation favours runoff into water bodies but also dilutes surface water; heavy rainfall can affect turbidity and re-suspend pathogens from sediment in water used for irrigation, processing, etc.	Not applicable
Pathogen occurrence and persistence on plants at harvest	Higher temperatures necessitate more frequent irrigation; growth and death rates are influenced by temperature	Not applicable	Heavy rains favour transmission of pathogens from soil to lettuce through splashing or flooding; irrigation soon after heavy rainfall events is more likely to be affected by contaminated runoff; droughts increase irrigation needs; precipitation can result in wet deposition of airborne pathogens on lettuce	Persistence and growth are favoured by high RH
Pathogen occurrence at processing	Not applicable	Increased surface water temperature can encourage pathogen growth in water used for food processing, if improperly treated	Rainfall can contaminate water used for lettuce processing if inadequately treated	Not applicable

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Pathogen persistence from processing through consumer storage	Growth rates are influenced by temperature; increased air temperatures can affect safe storage temperatures, thus encouraging pathogen growth	Not applicable	Extreme events can cause power outages, resulting in deficiencies in cold-chain management, and encourage pathogen growth	Not applicable
Consumer handling and preparation	Longer growing and, thus, longer consumption seasons increase annual exposure to Canadian-grown lettuce	Not applicable	Not applicable	Not applicable

The relationship between climate variables and lettuce contamination is complex; therefore, uncertainty exists about projected health risks due to climate change. For example, flooding and irrigation are two factors that may increase lettuce contamination, yet they are influenced by precipitation in opposite ways: increased rainfall could increase risks of contamination due to flooding or reduce risks due to less irrigation. More detailed analyses that capture the system's complexity in a particular context or location are required to understand how changes in precipitation will ultimately affect public health risks. Such analyses could include mathematical models, which could quantify the relative impacts of each risk driver on public health in the studied location and identify points throughout food systems where climate change adaptation measures could be most effective. By integrating climate change projections, the model could also allow various adaptation options to be tested (Romero-Lankao et al., 2014; ECCC, 2018).

8.5.1.1.1 Climate Change Impacts on Food Safety via Food Production

Food production (e.g., farming, aquaculture) is the stage of food systems where pathogens are most likely to be introduced and propagated through to food products. Climate change will create both challenges and opportunities for Canadian food production (Warren & Lemmen, 2014) and, therefore, may increase risks to food safety. For example, growing seasons may be extended and suitable land for agriculture may expand northward as temperatures rise (Schmidhuber & Tubiello, 2007; Gornall et al., 2010; Butler, 2014a; Warren & Lemmen, 2014; AAFC, 2015). At the same time, however, as climate conditions warm, pathogens can be introduced and become established in these new production regions via increased food production activity, range expansion of wildlife and insect vectors, and improved pathogen growth conditions (Séguin, 2008; Smith & Fazil, 2019).

Climate change can affect the release of pathogens from livestock into the environment (Smith & Fazil, 2019). Some livestock animals are known, or suspected to, carry and shed greater numbers of enteric pathogens during periods of elevated air temperatures (Venegas-Vargas et al., 2016). Increased temperatures expected with climate change may result in increased pathogen shedding (Keen et al., 2003; Pangloli et al., 2008), thus affecting pathogen abundance in the surrounding environment, crops, and, consequently, food. Increased temperature stress or alterations in livestock housing conditions (e.g., indoor versus outdoor environments) as a result of climate change could also drive increased antimicrobial use in food-producing animals, which could increase antimicrobial-resistant food-borne illnesses in humans (WHO, 2017; MacFadden et al., 2018).

Pathogens released into the environment can be transported via precipitation and directly contaminate food sources, such as crops or livestock facilities. The frequency and intensity of precipitation events is expected to increase for many regions in Canada as temperatures rise (Bush & Lemmen, 2019), increasing concerns about contamination. Without intervention, this contamination could work its way through all stages of food systems, ultimately contributing to the burden of food-borne illness. One study in Ontario, for example, found temporal associations between human giardiasis incidence and pathogen presence in manure in livestock reservoirs, river water level and flow rate, and precipitation (Brunn et al., 2019). As the climate continues to change, combinations of drought followed by extreme precipitation could increase these contamination events, as dry, compact soil has an increased runoff potential (Yusa et al., 2015).

Many wildlife and insect vectors, such as rodents, deer, flies, and beetles, contribute to food-borne pathogen transmission and therefore can affect food safety. Climate conditions can directly affect these vectors (Agunos et al., 2014). For example, climatic variables are known to affect fly population density (Goulson et al., 2005; Ngoen-Klan et al., 2011), and flies can be carriers of *Campylobacter* (Hald et al., 2008). In Ontario, a 28% to 30% increase in incidence of illness due to *Campylobacter* in humans is projected by 2050 due to climate-related changes in fly population size and activity (Cousins et al., 2019).

Warming water temperatures have been linked to seafood contamination and incidence of food-borne diseases. For example, modelling studies suggest that risks from *V. parahaemolyticus* in British Columbia could increase by 41% to 45% by the 2060s (Box 8.4) (Smith et al., 2015). In addition to *V. parahaemolyticus*, the abundance of *V. cholerae* detected along Canadian coasts has increased significantly over time (Banerjee et al., 2018). *V. cholerae* is a highly lethal pathogen (causing cholera) previously restricted to tropical regions, but its abundance could increase in Canadian waters with climate change.

Box 8.4 Projected impacts of climate change on *V. parahaemolyticus* in British Columbia oysters

Human exposure to *V. parahaemolyticus*, which occurs primarily through the consumption of raw oysters that contain the bacterium, causes gastroenteritis (Government of Canada, 2019). Approximately 2.33% of *V. parahaemolyticus* strains are pathogenic (FDA, 2005). Several of these pathogenic strains are present in seawater at and above 15°C and are known to concentrate in oysters that ingest the bacteria as they filter food from the water (Cabello et al., 2005; Konrad et al., 2017). Water temperature is the key environmental variable to which *V. parahaemolyticus* is sensitive (Young et al., 2015); thus, the prevalence and concentration of the bacteria vary seasonally and are expected to increase in many regions as air and water temperatures rise with climate change (Parveen et al., 2008; Grimes et al., 2009; Julie et al., 2010; Broberg et al., 2011; FAO & WHO, 2011).

A large portion of Canadian oyster production is located on the coast of British Columbia, with many operations in the Strait of Georgia between Vancouver Island and the British Columbia mainland (Comeau & Suttle, 2007). Despite careful harvesting and processing protocols intended to reduce the risk of contaminated oysters reaching consumers, projected changes in environmental conditions due to climate change in areas where oysters are farmed are likely to increase the presence and concentrations of *V. parahaemolyticus* and, therefore, the risk of human exposure and illness. These effects on oyster farming operations in British Columbia have been estimated via mathematical modelling, which is summarized in Table 8.6 (Smith et al., 2015).

Model results suggest that public health impacts from *V. parahaemolyticus* in oysters harvested in British Columbia, calculated in terms of disability-adjusted life-years (DALYs), could increase by 41% to 45% by the 2060s (Smith et al., 2015). In 2006, the burden of food-borne illness attributed to *V. parahaemolyticus* was 5.53 cases per 100,000 Canadians. The majority of these cases were assumed to be attributable to undercooked or raw shellfish; thus, if the projected relative increase in the burden of disease from *V. parahaemolyticus* in oysters applies similarly to other shellfish, then the public health burden could increase to eight cases per 100,000 Canadians in 40 years. Box 8.5 discusses adaptation options to reduce health risks from *V. parahaemolyticus*. Further development of models of *V. parahaemolyticus* and seafood risk may increase knowledge of the risks from climate change and support seasonal prediction capabilities and other health sector responses.

Table 8.6 Modelling the projected health risks of climate change impacts on *V. parahaemolyticus* in oysters

MODEL ELEMENT	DESCRIPTION
Location	• Chrome Island in the Strait of Georgia, British Columbia, Canada
Season	• Harvest spread equally among all months of the year
Pathogen	• *V. parahaemolyticus*, 2.33% of which are pathogenic (FDA, 2005)
Oyster species	• Farmed Pacific oyster, *Crassostrea gigas*
Environmental parameters affecting growth	• Water temperature pre-harvest, air temperature at harvest (oysters held at ambient air temperature two to 11 hours post-harvest), and temperature during refrigeration affect levels of V. parahaemolyticus
Climate change factors	• Increase of mean harvest water temperature by 0.024°C per year • Increase of daily maximum air temperature by 0.04°C or 0.08°C per year
Human exposure	• Dose–response model used with mass of oysters consumed per serving and number of servings per year
Health outcomes	• Rate of infection with gastrointestinal illness and DALYs attributed to *V. parahaemolyticus* in oysters
Results	• DALYs associated with *V. parahaemolyticus* in oysters harvested in British Columbia are estimated to increase by 41% to 45% by the 2060s • This would correspond to an increase to eight cases per 100,000 Canadians from *V. parahaemolyticus* in all shellfish by the 2060s

Source: Adapted from Smith et al., 2015

8.5.1.1.2 Climate Change Impacts on Food Safety via Food Processing and Distribution

Climate variables also affect the occurrence, growth, and survival of pathogens throughout food processing and distribution. Any pre-existing contamination can proliferate if food is mishandled during these steps (e.g., inappropriate food storage temperature, cross-contamination), and additional contamination can be introduced through, for example, the use of contaminated water during processing (see Chapter 7: Water Quality, Quantity, and Security). Extreme weather events associated with climate change, such as flooding, high winds, or precipitation can result in power outages that disrupt temperature controls (e.g., refrigeration), creating opportunities for pathogen growth and resulting in impacts on food safety and food-borne illnesses.

Air temperature is a key food safety risk during food processing and distribution. The prevalence of poultry contaminated with *Campylobacter* in Canadian processing and retail environments has been positively correlated with air temperatures (Smith & Fazil, 2019). Humidity and precipitation also affect the occurrence of pathogens throughout processing and distribution. For example, some micro-organisms, such as fungi, can produce mycotoxins that cause adverse human health effects, and these micro-organisms can proliferate under certain temperature and humidity conditions during the processing of corn and cereal grain products (Duarte et al., 2010). In Canada, warmer and wetter conditions due to climate change could encourage fungi growth and mycotoxin production (Patriarca & Fernández Pinto, 2017).

Nearly 30% of retail food consumed in Canada is imported from other countries (Statistics Canada, 2009); therefore, any climate-related changes to the occurrence or growth of pathogens during food production in other countries, or during food distribution to Canada, could affect the health of Canadians. Cases of food-borne illness caused by pathogens previously exotic or rare to Canada could increase in incidence with climate change (Smith & Fazil, 2019). Canadian food importers, along with federal, provincial, and local public health agencies, should enhance the monitoring of global trends and incidence of food-borne illness to anticipate potential new threats to Canadian food systems. Environmental scanning platforms, such as the Canadian Food Safety Information Network, may assist with such monitoring, as they include tools to identify local or global food safety issues (CFIA, 2018). Additionally, international initiatives, such as the European Food Safety Authority's Climate Change and Emerging Risks for Food Safety project, which lists climate-related emerging risks in European food systems (EFSA et al., 2020), may be helpful in informing and monitoring existing and emerging food safety risks relevant to Canada. Given the interconnected nature of the global food system, and the complex effects climate change has on food systems, monitoring may become increasingly challenging and may need to expand in order to appropriately capture the diverse impacts of climate change on food safety in Canada.

8.5.1.1.3 Climate Change Impacts on Food Safety via Food Preparation and Consumption

Climate change impacts on food-borne illnesses at the preparation and consumption stages fall into three categories: climate-related behavioural changes by individuals that increase pathogen exposure via food; increased pathogen survival and growth on foods during transport or storage; and potential indirect climate-related changes to human susceptibility and/or exposure to food-borne illness.

Human behaviour, such as food mishandling events, can lead to cross-contamination or undercooking of food products, thus increasing the risk of food-borne illness. Seasonal increases in food mishandling by consumers are attributable to higher-risk cooking methods (e.g., barbeque used in the summer may increase risk of cross-contamination if the same utensils are used for raw and cooked meats) and consumption patterns (e.g., picnics in warm temperatures where foods are less likely to be stored at safe temperatures) (Ravel et al., 2010; Liu et al., 2013; Milazzo et al., 2017). In Canada, the contamination of meat products with *Salmonella* spp. does not increase in the summer season, compared to the rest of the year (Smith & Fazil, 2019); however, human cases of illness caused by *Salmonella* do increase in the summer (Fleury et al., 2006; Ravel et al., 2010; Valcour et al., 2016), suggesting that behavioural factors and/or susceptibility could drive the seasonality of illness rates (Ravel et al., 2010). Climate change could also influence food preferences and consumption patterns, which may have implications for human health. For example, an extended growing season, due to climate change, could provide longer access to fresh produce, which is at increased risk for pathogen contamination due to higher temperatures and changes to precipitation, thus increasing the risk of food-borne illness. In fact, the rate of *E. coli* outbreaks linked to raw produce (e.g., lettuce) has increased over the last several decades (Rangel et al., 2005; Heiman et al., 2015).

Storing foods at cold temperatures at which pathogens cannot grow is one of the main strategies to maintain food safety. Even a 1°C increase in average ambient temperatures, which has already been surpassed in Canada due to climate change (see Chapter 1: Climate Change and Health Linkages), can result in significant food safety concerns (Smith et al., 2015). Furthermore, the projected increase in extreme weather events and resulting power transmission disruptions due to climate change (Warren & Lemmen, 2014) will introduce potential disruptions in the cold chain at the consumer level with subsequent increases in food safety risk. In Northern Canada, safe food storage in ground freezers used by some Indigenous Peoples is threatened by increasing temperatures and permafrost thaw (CCA, 2014).

Finally, other adverse health effects caused or exacerbated by climate change can increase an individual's susceptibility to food-borne illnesses. For example, immunocompromised individuals are at increased risk of an infectious illness, including from food-borne pathogens (Pouillot et al., 2015). Furthermore, malnutrition arising from food insecurity, extreme weather events (e.g., extreme heat events, flooding), and poor air quality can cause adverse health impacts on Canadians, which could compound vulnerability to food-borne illness (Kipp et al., 2019).

8.5.2 Climate Change Impacts on Food Safety via Chemical Contaminants

Food-related chemical hazards occur when chemicals are present in foods at levels that negatively affect human health when consumed (CFIA, 2014). Chemical contaminants include a wide range of compounds, such as persistent organic pollutants (POPs) (e.g., industrial chemicals, pesticides), heavy metals (e.g., arsenic, copper, cadmium, lead, mercury, tin), and polycyclic aromatic hydrocarbons (PAHs). These chemical contaminants are introduced into plants and animals through environmentally mediated pathways, such as atmospheric deposition and uptake from contaminated soil, water, or other organisms. For example, when chemical contaminants are deposited at or near sites of food production or harvesting, such as fish breeding grounds, livestock pastures, or agricultural lands, they can be introduced into food systems via contaminated water or soil (Thomson & Rose, 2011). Levels of chemical contaminants in commercial foods are monitored through regular surveillance activities by Health Canada and the Canadian Food Inspection Agency. Chemical contaminants may be detected in commercial foods; however, concentrations are generally low and not associated with adverse health impacts. Canada's national food chemical safety program has various tools (e.g., monitoring and surveillance programs, guidance on maximum safe concentration levels, and consumption advice) to help ensure exposure to food chemical contaminants is as low as possible.

There is growing evidence that climate change could increase human exposure to chemical contaminants, as climate variables, such as temperature, precipitation, wind, hydrological systems, ice and snow coverage, and extreme weather events can affect the transport, distribution, concentration, persistence, and bioaccumulation of chemical contaminants (Dewailly et al., 2000; Jaykus et al., 2008; Rose et al., 2011; Marvin et al., 2013; CCA, 2014; Manciocco et al., 2014; Government of Canada, 2016; Ziska et al., 2016).

8.5.2.1 Climate Change Impacts on Contaminants Throughout Food Systems

Environmental contaminants are chemicals that accidentally or deliberately enter the environment, often, but not always, as a result of human activities. Some of these contaminants may have been manufactured for industrial use and, because they are very stable, they do not break down easily. If released into the environment, these contaminants may enter the food chain. Other environmental contaminants are naturally occurring chemicals, but industrial activity may increase their mobility or increase the amount available to circulate in the environment, allowing them to enter the food chain at higher levels than would otherwise occur. Levels detected in food sold in Canada are generally low. These contaminants have varying toxicity and health effects (Government of Canada, 2016). For example, food-borne exposure to POPs has been linked to cancer, negative effects on the immune system, and developmental and reproductive problems (Schecter & Gasiewicz, 2003; Pardue et al., 2005; Government of Canada, 2016; Weihe et al., 2016). Exposure to food-borne heavy metals, such as lead and mercury, can affect the nervous system and cause cognitive, behavioural, and motor impairments (ATSDR, 1999; Thomson & Rose, 2011; Boucher et al., 2012; ATSDR, 2020; Dewailly et al., 2000; USEPA, 2021). More than 80% of fish consumption advisories in Canada and the United States are at least partially attributed to methylmercury (Eagles-Smith et al., 2016), which bioaccumulates in aquatic organisms and can cause severe health effects when consumed by humans in sufficiently high quantities or over prolonged periods of time (Alava et al., 2018). Biotoxins in the food system that can cause health risks to Canadians, and that are linked to climate change, are discussed in more detail in Chapter 7: Water Quality, Quantity, and Security.

Multiple factors contribute to the potential risk and severity of illness resulting from chemical contaminant exposure, including an individual's genetic predisposition and other health conditions, the contaminant type and concentration, and the extent of exposure over time (Ziska et al., 2016). Risks are increased in children and seniors, since their organ systems have a reduced ability to process and eliminate contaminants (Lopez & Goldoftas, 2009; Ferguson et al., 2017).

8.5.2.1.1 Climate Change Impacts on Food Safety via Chemical Contamination During Food Production

In Canada, the impact climate change has on food safety via chemical contamination is not well understood, and the extent of increased risk has not been quantified. For example, additional research is required to monitor whether climate change will increase concentrations of contaminants to levels that may be associated with adverse health effects. International evidence suggests that climate change is likely to increase the risk of chemical contamination during food production through several pathways (Thomson & Rose, 2011) (Table 8.7).

Table 8.7 Examples of environmental chemical contaminants, potential adverse health effects,[2] and mechanisms through which climate change may increase global food safety risks

CHEMICAL CONTAMINANT	EXAMPLE ADVERSE HEALTH EFFECTS	CLIMATIC EVENT	IMPACTS OF CLIMATIC EVENT	POTENTIAL FOOD SYSTEM RISKS
Arsenic	*Acute:* nausea; vomiting; diarrhea; cardiovascular effects; adverse brain effects *Chronic*: dermal effects; numbness in hands and feet; skin, bladder, and lung cancer	Flooding	Transport from contaminated sites to agricultural land	Uptake into foods grown in contaminated sites (e.g., agricultural crops, livestock grazing sites)
		Drought	Need to use wastewater for irrigation	More contaminants applied to crops
Cadmium	Kidney and bone damage; cancer	Freshwater warming	Increased uptake and bioavailability	Higher concentration in the food chain
Polychlorinated biphenyls (PCBs)	Cancer; endocrine disruption; immune, neurological, and reproductive effects	Oceanic warming	Increased Arctic algal growth	Higher concentration in food chain
		Warmer, drier summers	Need to use wastewater for irrigation	More contaminants applied to crops
Dioxins and dioxin-like PCBs	Skin lesions; cancer; endocrine disruption; immune, neurological, and reproductive effects	Flooding	Transport from contaminated sites to agricultural land	Uptake into milk, eggs, and other animal products

2 The examples of health effects associated with chemical contamination in this table are generally associated with much higher concentrations of contaminants than levels to which Canadian populations are typically exposed. While exposure to some contaminants may increase as a result of climate change in Canada, ongoing monitoring and surveillance is needed to determine whether levels would increase high enough to be associated with adverse health effects.

CHEMICAL CONTAMINANT	EXAMPLE ADVERSE HEALTH EFFECTS	CLIMATIC EVENT	IMPACTS OF CLIMATIC EVENT	POTENTIAL FOOD SYSTEM RISKS
Lead	Hematological, gastrointestinal, cardiovascular, renal, neurological, and reproductive effects; impaired metabolism of vitamin D in children	Flooding	Transport from contaminated sites to agricultural land	Uptake into pastoral foods
Mercury/ methylmercury	Impaired neurological development; impaired peripheral vision; sensory disturbances; coordination loss; impaired speech, hearing, and walking; muscle weakness	Oceanic warming	Increased Arctic algal growth and methylation	Higher concentration in fish
		Wildfires	Release of sequestered mercury from soil	Increased uptake in foods via atmospheric deposition
Polycyclic aromatic hydrocarbons (PAHs)	Cancer	Floods	Transport from contaminated sites to agricultural land	Uptake into pastoral foods
		Wildfires	Increased formation of PAH	Increased uptake in food via atmospheric deposition
		Warmer drier summers	Need to use wastewater for irrigation	More contaminants applied to crops

Source: Adapted from Thomson & Rose, 2011

Increasing temperatures associated with climate change are expected to exacerbate the risks posed by POPs, which are already of concern due to their negative health effects (WHO, 2008). Projected warming will enhance the transfer of POPs from oceans, lakes, and rivers to air, which will subsequently extend the potential for long-range transport of POPs (Ma et al., 2011). Climate change is also expected to influence soil properties and thereby increase the bioavailability of POPs and heavy metals and increase their bioaccumulation in food chains (Boxall et al., 2009; Manciocco et al., 2014). Similar trends are anticipated for PAHs in a changing climate (Miraglia et al., 2009).

Increasing extreme weather events associated with climate change will also affect the distribution of chemical hazards in the environment. Heavy precipitation and flooding can transport chemicals from direct sources (e.g., mines and tailing ponds), as well as contaminated soils, to new locations where food is produced (Lake et al., 2005; Boxall et al., 2009; Miraglia et al., 2009; Umlauf et al., 2011; Lake et al., 2015). European studies have found that regular flooding of industrial river catchments increase polychlorinated dibenzo-p-dioxins dibenzofurans (PCDD/Fs) and polychlorinated biphenyl (PCB) levels in soil and grass, which can then be transferred to food (Umlauf et al., 2011; Lake et al., 2015). Similarly, researchers found high levels of POPs in soil from flooded pastureland and in the milk of animals that grazed on the land (Umlauf et al., 2005), as well as high levels of cadmium and lead in wheat, lettuce, and potatoes (Lake et al., 2005). Wildfires have also been identified as a pathway for food source contamination, as they release PAHs and other contaminants (e.g., dioxins, cadmium, and mercury) into the air, which can then travel long distances before they are deposited (Armitage et al., 2011). If these chemicals are deposited into water bodies or on agricultural or pastureland, they could be introduced into food systems. Additional research on the impact of wildfires on chemical contamination of food is needed.

Rising water temperatures also exacerbate levels of seafood contaminants (e.g., nickel, copper, cadmium, lead, and zinc) and risks to aquatic organisms (Ma et al., 2011; Manciocco et al., 2014). For example, rising water temperatures can increase PCB metabolites and copper toxicity in rainbow trout (Boeckman & Bidwell, 2006; Khan et al., 2006; Buckman et al., 2007; Manciocco et al., 2014). Increasing water temperatures also affect concentrations of methylmercury in fish and mammals (Carrie et al., 2010) as a result of increased metabolic rates and mercury uptake (Booth & Zeller, 2005; Ziska et al., 2016).

Climate change is projected to increase the incidence of livestock and aquatic pests, parasites, and microbes (Lafferty et al., 2004; Ziska et al., 2016), which could encourage greater use of pesticides, herbicides, veterinary treatments, and aquaculture drugs (Boxall et al., 2009; Tirado et al., 2010; AAFC, 2015; Ziska et al., 2016). This increased incidence is projected to be exacerbated as chemicals used for pest management, such as pesticides and herbicides, become less effective as concentrations of CO_2 increase (Ziska et al., 2016). Such changes could lead to increased chemicals from pesticides, herbicides, and veterinary drugs entering food systems, with negative implications for human health (Boxall et al., 2009; Miraglia et al., 2009; Manciocco et al., 2014; Delcour et al., 2015).

Greater demand for water resources to maintain agricultural activities is expected as a result of changing precipitation patterns and the projected increase in droughts in many regions of the world (Jiménez Cisneros et al., 2014). Indeed, some regions are already experiencing stress on water resources and increasingly turning to wastewater reuse to meet irrigation needs. Wastewater can contain chemicals, such as PAHs and PCBs, which can therefore enter the food chain when used to irrigate agricultural crops (Al Nasir & Batarseh, 2008; Rose et al., 2011). Although wastewater is not commonly used in Canada for crop irrigation, stressed water resources and response measures could lead to food safety risks in the future and should be monitored. Further, policies and regulations for wastewater use and other water management practices vary by country, which has implications for the safety of foods being imported into Canada (Lake et al., 2012).

8.5.2.1.2 Climate Change Impacts on Food Safety via Chemical Contamination During Food Preparation and Consumption

While there is limited research examining how climate change could affect chemical contamination during food preparation and consumption, human behaviours may change in response to climate change in ways that could increase chemical exposures. For example, processing foods (e.g., drying, smoking) and cooking foods at high temperatures (e.g., grilling, frying, roasting, baking) are common sources of food contamination by PAHs and heterocyclic amines (Sugimura et al., 2004; Zelinkova & Wenzl, 2015). Consequently, the potential increase in barbequing associated with more frequent and prolonged warm days could increase exposure to chemicals from barbequed foods (Séguin, 2008).

Some Indigenous communities in Canada have developed alternative gardening and food preservation measures in an effort to adapt to climate change. Such activities may be necessary to support individual and community food security and sovereignty but may have unintended implications for human health. A study of food-related climate adaptation activities implemented, or planned to be implemented, across three First Nations communities in British Columbia and one Inuit community in Nunavut, revealed several food safety concerns (Steiner & Neathway, 2019). These included PAH contamination from food smoking, chemical contamination from the use of tires or treated wood as planters, and chemical and microbial risks from the use of greywater for crop irrigation (Steiner & Neathway, 2019). More research is needed to understand how such climate change adaptation measures may affect food safety and human health.

8.5.2.2 Climate Change Challenges Related to Chemical Hazards in Foods in the Arctic and Sub-Arctic

Persistent contaminants are found throughout Northern ecosystems, largely from transport from lower latitudes through air, water, and terrestrial routes (Kuhnlein & Chan, 2000; Rigét et al., 2016; Brown et al., 2018), and from local sources (e.g., mining sites). For example, accelerated temperature rise and the consequent melting of glaciers, snow, and sea ice can enhance POP transfer between trophic levels, and increase food safety risks for Arctic populations (Ma et al., 2011; Manciocco et al., 2014). Chemical contaminants deposited and trapped in glaciers via airborne transportation may be deposited in glacier-fed lakes and water bodies as glaciers melt, increasing exposure to humans and wildlife (Bogdal et al., 2009).

In Northern regions, locally harvested foods can be a significant route of contaminant exposure (Ratelle et al., 2018), particularly for Indigenous Peoples, as Indigenous food systems in the Arctic and sub-Arctic often include large quantities of locally harvested fish, birds, and marine mammals. Fish and marine mammals are primary sources of mercury and PCBs (NCP, 2013; Rigét et al., 2016; Brown et al., 2018; Chukmasov et al., 2019). Similarly, POPs and heavy metals have been found in all components of the Arctic ecosystem (Fillion et al., 2014). Once an organism absorbs a contaminant, the contaminant can bioaccumulate in the organism or be transferred to other organisms, posing potential health risks to those who consume the organism in significant quantities or over an extended period of time (Dewailly et al., 2000; NCP, 2013).

Variations in contaminant body burdens commonly reflect differences in dietary habits and traditional lifestyles (AMAP, 2015; Government of Canada, 2017). For example, POP and metal levels in Inuit women are generally higher for those in coastal communities in Nunavik and Nunavut, where there is a higher consumption of marine mammals, compared with Inuit women from Nunatsiavut (in Northern Labrador) and the Inuvialuit Settlement Region (in the Northwest Territories) (Government of Canada, 2017). Results of the *Inuit Health Survey (2007–2008)* suggest that Inuit men tend to eat traditional foods more frequently and in larger quantities than Inuit women (Egeland, 2010). The body burden of POPs and metals were therefore often higher in Inuit men than women, sometimes as much as two-or three-fold. Likewise, older adults typically consume more traditional foods than younger adults, and generally have higher contaminant body burdens of POPs and metals (Government of Canada, 2017). Globally, coastal Indigenous Peoples consume on average 15 times more seafood per capita than non-Indigenous people (Cisneros-Montemayor et al., 2016), and thus may be at increased risk of climate-related alterations in contaminant concentrations in food systems.

With warmer temperatures leading to earlier sea ice breakup, the toxicity of some contaminants in the water column may increase (Gaden et al., 2012). High levels of mercury and PCBs in Arctic fish have been linked to enhanced algal growth from warmer water temperatures (Carrie et al., 2010). Climate-related shifts in prey type and abundance could also affect contaminant exposure in marine mammals, by affecting foraging times and success. Earlier spring sea ice breakup can allow marine animals to forage earlier and for longer periods and allow access to foraging areas that were inaccessible under previous breakup regimes (Gaden et al., 2012).

Exposure to PCBs and mercury in top predatory species may increase with climate change, as Arctic sea ice retreats and releases accumulated chemicals to marine environments (Gaden et al., 2012; Alava et al., 2018). One study projected that the concentration of methylmercury and PCBs in animals at high trophic levels could increase by 8% and 3% by 2100 under a high emissions scenario (RCP8.5) and a no climate change scenario, respectively (Alava et al., 2018). Another study found a 3% to 5% increase in methylmercury uptake in marine organisms for each 1°C rise in water temperature (Booth & Zeller, 2005). In addition to food safety risks, the nutritional value of fish (e.g., omega-3 fatty acids) may also change due to interactions between climate change and contaminants and effects on fish metabolism (Alava et al., 2017). Climate change may, therefore, increase exposure to chemical contaminants in, and change the nutritional quality of, important food sources harvested by Indigenous Peoples (Undeman et al., 2010). Consumption of traditional foods have significant importance for the health and well-being of Indigenous Peoples (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Guidance from the Government of Canada's *Canadian Arctic Contaminants Assessment Report* and the Arctic Monitoring and Assessment Programme suggest that the nutritional benefits from consumption of traditional foods outweigh potential risks associated with chemical contamination, with few exceptions (Chukmasov et al., 2019). As the climate changes, it will be important to enhance research efforts and increase understanding of the impacts of climate change on food safety via chemical contamination.

8.6 Adaptation to Reduce Health Risks

Adaptation is a key component of the response to climate change in Canada and globally and has been identified as an urgent need to protect health (see Chapter 10: Adaptation and Health System Resilience). Responsibility for adaptation in Canada is divided between federal and provincial/territorial governments (Berry et al., 2014a; Henstra, 2017). Many adaptation measures focused on food security and food safety fall within the jurisdiction of public health, which is both a federal issue that crosses provincial and territorial borders, and a sub-national issue that falls under provincial health jurisdiction (Austin et al., 2018). Each province and territory has its own organizational structure, policy direction, and priorities for delivering public health services, determining how adaptation to the effects of climate change on food security and food safety is approached (Clarke & Berry, 2012). Regional and local public health authorities also play a critical role in maintaining food safety through health protection, promotion, screening, and surveillance (Berry et al., 2018).

Adaptation at the food–health nexus will require intersectoral collaboration (e.g., health, environment, agriculture, transportation), and coordination across multiple levels of government and with civil society (Hess et al., 2012; Berry et al., 2014a; Smith et al., 2014). Food systems are complex webs of interdependent factors that affect food safety and food security and are often transboundary in nature (e.g., involving human behaviour, trade, and regulation) (Challinor et al., 2017). Adaptation policy responses that lack high levels of coordination across sectors risk being redundant, fragmented, or maladaptive (Magnan et al., 2016; Austin et al., 2018).

Recognizing the diversity of adaptation opportunities for food systems, this chapter examines two types of adaptation: climate-centred adaptations, which have a narrow and substantial focus on responding to food-related impacts of biophysical hazards associated with climate change; and vulnerability-centred adaptations, which have a broad and integrative focus on the societal, cultural, environmental, political, and economic factors (i.e., social determinants of health), that create and exacerbate vulnerability to food-related impacts of climate change (Ebi, 2009; Dupuis & Biesbroek, 2013; Ford et al., 2018). To address climate-related health risks relevant to food security and safety in Canada both climate- and vulnerability-centred adaptations are needed.

8.6.1 Climate-Centred Adaptation Options

8.6.1.1 Climate Change and Health Vulnerability and Adaptation Assessments

Vulnerability and adaptation assessments (V&As) concerning climate change and health provide an evidence-based assessment of the key health risks posed by climate change, identify high-risk populations and regions, evaluate the effectiveness of existing interventions, and outline adaptation opportunities (Berry et al., 2014a; Buse, 2018). These assessments are critical to building public health preparedness for climate change (Charron et al., 2008; Hansen & Hoffman, 2011; Berry et al., 2014a; PHAC, 2017; Berry et al., 2018). Regional and local health authorities across Canada are increasingly conducting V&As; however, the degree to which climate-related impacts on food security and food safety are assessed varies.

Provincially and territorially, responsibility for completion of V&As reflects mandates for climate change adaptation and the jurisdictional landscape for health services. Under the Ontario Public Health Standards, for example, health units are required to assess the health impacts of climate change. Several health units have, therefore, completed V&As, including Grey Bruce Health Unit (Grey Bruce Health Unit, 2017), Middlesex-London Health Unit (Berry et al., 2014b), and Simcoe Muskoka District Health Unit (Levison et al., 2017), all of which address risks of food-borne illness. Both assessments from Middlesex-London Health Unit and Simcoe Muskoka District Health Unit also explicitly consider the multiple dimensions of food security. The City of Toronto's report, *Exploring Health and Social Impacts of Climate Change in Toronto* (Medical Officer of Health, 2013) considers food security and food safety in the context of power outages during extreme weather events and insufficiency of food storage standards as temperatures warm. In 2017, Toronto Public Health launched a Food Vulnerability Assessment (Zeuli et al., 2018a) to assess the resilience of Toronto's food system under three extreme weather scenarios. Although food security risks were relatively low, they were associated with extreme weather events. The city identified a need to develop food resilience plans for neighbourhoods already experiencing food insecurity, which could be exacerbated by climate change. The report included recommendations to develop poverty-reduction strategies that address unequal food access (Zeuli et al., 2018a).

There are challenges in developing robust, actionable food-related V&As. Climate change and health V&As rely on surveillance data to assess associations between health outcomes and climatic conditions. While surveillance systems are in place to identify food-borne illnesses, the majority of cases of food-borne illness are undiagnosed or unreported (Berry et al., 2014a; Harper et al., 2015c; Thomas et al., 2015). Furthermore, while there have been advances in climate projections and impact analysis, particularly in localized downscaled projections, uncertainty regarding projections of food-borne disease in Canada due to climate change remains high. As a result, many V&As do not quantify how climate change may affect food-related risks, and, where future trends are examined, they involve only general extrapolations indicating the potential direction of change (Ebi et al., 2018). Furthermore, links among climate change, food quality, and water quality remain understudied (PHAC, 2017). Therefore, there is a need for future studies to examine how projected climate changes will affect food security and food safety (Smith & Fazil, 2019), and how future demographic and socio-economic factors will affect the distribution and incidence of such risks in Canada.

Several programs have been initiated in response to these gaps. For instance, the Public Health Agency of Canada's Preventative Public Health Systems and Adaptation to a Changing Climate Program is focused on working with public health stakeholders to expand research on climate change impacts and to support adaptations, including surveillance and response to emerging food-borne diseases. In addition, Health Canada's climate change and health adaptation capacity-building program, HealthADAPT, has funded 10 projects across Canada that aim to improve the knowledge base about the health impacts of climate change and develop strategic adaptation plans to address risks by conducting V&As. Partners in these projects include provincial and territorial health ministries, local health units, and the First Nations Health Authority in British Columbia. Several of these projects will examine climate change impacts on food-borne diseases.

8.6.1.2 Adaptation Planning

Climate change adaptation strategies and action plans play important roles in linking evidence to decision-making, articulating policy goals and objectives, and establishing pathways for adaptation action (Olazabal et al., 2019). Adaptation plans are a key component in laying the groundwork for adaptation action in all levels of government in Canada, minimizing climate-related impacts on food security and food safety, and maximizing resilience-building efforts. However, achieving tangible benefits from these groundwork efforts necessitates effective and timely implementation (Lesnikowski et al., 2011; Lesnikowski et al., 2016).

Discussions about intersections among climate change, food security, and health are often better developed in strategic adaptation plans for Indigenous communities, where changing environmental conditions are affecting Indigenous food systems (Box 8.5). For example, Newfoundland and Labrador's climate change plan highlights the links between temperature and sea ice changes, on one hand, and decreased access to Inuit hunting areas, on the other, and implications for Inuit food security, safety, and mental health outcomes (Municipal Affairs and Environment, 2019). Food is also a key priority in territorial adaptation planning, where cross-sectoral adaptation actions are being designed to integrate health, conservation, economy, and culture. In many provincial climate change adaptation strategies, however, climate-related impacts on agricultural production are framed as an economic, rather than a public health, issue. In Nova Scotia, for example, adaptation activities in the Department of Agriculture focus on crop diversification, soil and water management, pest control, and flood risk management, but do not make explicit linkages with public health risks related to food security and food safety (Nova Scotia Environment, 2014).

Despite its importance, municipal climate change planning is highly uneven across Canada (Guyadeen et al., 2019). Examples of municipal adaptation plans that address growing climate change risks to food include Toronto's Climate Change and Health Strategy, which sets out several actions that build on the Toronto Food Strategy, including identifying the need for infrastructure to support food system sustainability, encouraging low-carbon diets, and assessing climate change impacts on food security and food safety (TPH, 2015). The City of Surrey, in British Columbia's agriculturally productive lower mainland, has examined how changing temperatures and precipitation will affect agricultural losses and increase the risk of food-borne illness. The city's Agricultural Plan was updated in 2013 to reflect changing climatic conditions (Planning and Development Department, 2013). Surrey's Climate Adaptation Strategy aims to improve local resilience to climate-related disruptions in global food prices and supply chains by encouraging crop diversification and supporting local research on climate-resilient agricultural practices. The strategy also draws linkages with long-term flood risk management and land-use planning mechanisms to improve food production in urban spaces. At the regional level, Metro Vancouver's Food Action Plan Task Force is working to identify how municipalities throughout the region are contributing to a resilient regional food system, and how local food-production capacity can be increased (Metro Vancouver, 2016). Some small towns and rural areas are also examining how local food systems will be affected by climate change. The City of Castlegar, British Columbia, conducted a Sensitivity Assessment for Food and Agriculture that examined how climate change will stress local food production (City of Castlegar, 2010). The assessment proposed several actions to improve the adaptive capacity of Castlegar's food system to climate change, including citizen-based monitoring of crop production and awareness-raising about food storage techniques.

In Quebec, the city of Montréal is conducting a study on the potential for urban commercial agriculture on the island of Montréal that supports food system resilience, with the goal of developing a commercial urban agriculture strategy and action plan (Ville de Montréal, 2018). However, in the general context of climate change planning, municipal policies regarding food production and consumption have commonly been adopted with the goal of reducing GHG emissions, and only recently are Canadian cities beginning to integrate food production and consumption into adaptation planning. For instance, some local adaptation strategies now recognize that higher summer temperatures and power outages due to extreme weather events pose a threat to food safety by increasing the risk of food-borne illness (Halifax Regional Municipality, 2010; City of Windsor, 2012; City of Montréal, 2015; City of Toronto, 2019). Municipal strategies that consider food security in the context of climate change often focus on increasing the self-sufficiency of local and regional food systems; food systems can be a nexus that provides opportunities to achieve synergies between adaptation and GHG mitigation policies (City of Toronto Environment Office, 2008; City of Surrey, 2013; Zeuli et al., 2018b).

To support adaptation by Indigenous communities, the First Nations Adapt Program and the Climate Change Preparedness in the North Program, administered by Crown-Indigenous Relations and Northern Affairs Canada, funds Indigenous-led climate change risk assessments and supports the development of adaptation options (CIRNAC, 2018; CIRNAC, 2019). Many of the funded projects have focused on climate-related impacts on health and/or food security. Examples include projects led by the Blood Band in Alberta to increase awareness about the impact of climate change on community food security; in British Columbia, the Splatsin First Nation's risk assessment on the impact of flooding on food resources; the Government of Yukon Department of Environment's research on the relationships among climate change, traditional foods, and Yukoners' diets; and a permafrost vulnerability assessment and map of traditional harvest areas conducted by the Jean Marie River First Nation with Yukon College. The Climate Change and Health Adaptation Program, administered by Indigenous Services Canada, also funds community-driven projects to build adaptive capacity for the health impacts of climate change, including a number of projects on food security.

Efforts are underway at all governmental levels to address climate-related impacts on food production and security. Opportunities exist to learn from leading projects and partners that explicitly address risks to health and that expand protection of Canadians from future climate change impacts. These actions would encourage collaborative partnerships across sectors and inform more effective adaptation action, contributing to greater resilience in the population.

8.6.1.2.1 Adaptation Leadership in Northern Canada to Address Risks to Food Security and Safety

In Northern Canada, adaptation planning is taking place at regional to community levels. Formal planning efforts share a common perspective on climate-related health impacts as a cross-cutting challenge and emphasize the need to understand and respect relationships among health, conservation, culture, and the economy. The integration of Western science and Indigenous knowledge is a key principle found across planning documents, although a dominance of scientific framings and government planning approaches has been noted (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada) (Bates, 2007; Cameron et al., 2015; Labbé et al., 2017; Flynn et al., 2018). Key food-related impacts of climate change addressed in many Northern adaptation plans include changes in the availability and accessibility of traditional foods, increased contaminants, more unpredictable weather and sea ice conditions, and impacts on mental health outcomes from challenges in preserving Indigenous practices and skills embedded in land-based activities.

At the regional level, the Pan-Territorial Adaptation Strategy (Government of Nunavut et al., 2011) has encouraged cooperation among the territorial governments to understand climate change risks and propose appropriate policy response measures. Inuit Tapiriit Kanatami's National Inuit Climate Change Strategy (ITK, 2019) aims to enhance coordination of Inuit regional adaptation planning efforts and develop strong linkages between global advocacy and participation in local efforts. The plan identifies five priority action areas: knowledge and capacity development; health, well-being, and the environment; food systems; energy; and infrastructure. Additionally, the National Inuit Committee on Health convenes an Inuit Food Security Working Group, which coordinates efforts around nutrition, food security, and health in Inuit regions.

Strategic frameworks and action plans have also been adopted or are currently being developed at territorial and local levels. For example, the Northwest Territories Climate Change Strategic Framework and its associated Action Plan (2019 to 2023) detail several adaptation actions that specifically target food security and health, such as monitoring Indigenous food sources, conducting surveillance of species distribution, geo-mapping food system contamination, monitoring drinking water quality, developing a health advisory alert system, and exploring the potential for cultivation of new crops in community gardens as the growing season lengthens (Government of Northwest Territories, 2018). The Framework and Action Plan highlight that Indigenous knowledge should be used to obtain baseline data to monitor environmental and health trends and to identify future research needs. Both the Government of the Northwest Territories Sustainable Livelihoods Action Plan for 2019 to 2023 and the Nunavut Food Security Strategy and Action Plan for 2014 to 2016 also recognize that climate change poses a key risk to food accessibility in the region and state the importance of ensuring access to country foods to achieve community food security.

The Government of Nunavut's strategic document *Upagiaqtavut – Setting the Course: Climate Change Impacts and Adaptation in Nunavut* emphasizes community involvement, decision-making by consensus, collaboration, resourcefulness, and respect for the environment. The document proposes several outreach and research activities, including planning toolkits, incorporating climate change topics into school curricula, and encouraging knowledge-sharing from Elders to youth. A number of community-specific actions to increase food access were developed through community adaptation planning exercises with federal and territorial government support, including delivering hunter apprenticeship programs, repairing or replacing dangerous trails to provide access to hunting and fishing areas, improving access to navigation technology and equipment, establishing community freezers, and creating awareness programs for safe food storage. Based on the results of these projects, a Local Adaptation Planning in Nunavut Toolkit was released in 2011 to support communities preparing their own adaptation plans (Bowron & Davidson, 2011).

The Government of Yukon is developing a territorial adaptation strategy that builds on past adaptation work. The Climate Change and Public Health Project (2013–2014) identified current and projected climate change health impacts in Yukon, along with priorities and gaps in knowledge and resources (Government of Yukon, 2014). Regarding food policy more broadly, the territory established an Interdepartmental Food Security Working Group to propose pathways forward for addressing food security across the portfolios of the Departments of Environment; Health and Social Services; Economic Development; Community Services; Energy, Mines and Resources; and Education. The territory is also developing a local food strategy, intended to encourage regional production and consumption of food and to reduce reliance on food transported from outside of Yukon. Various actions have been proposed to increase Yukon's food system resilience, including the expansion of community markets, funding for irrigation system upgrades and specialized farming equipment, and the design of school programs to engage students on issues of food sustainability in Yukon, all of which will also enhance climate change adaptive capacity.

8.6.1.3 Surveillance

Surveillance systems are critical components of adaptation to the health impacts of climate change (Ebi & Semenza, 2008; Lam et al., 2019), as they provide ongoing monitoring of health outcomes through the collection, analysis, and interpretation of data. While most surveillance systems in Canada related to food safety do not currently include climate variables and were not implemented to support climate change adaptation, it is possible to use climate information and surveillance results to better understand risks to health and evaluate adaptation options (Box 8.5). For example, Smith et al. (2019) used national surveillance data from the Canadian Integrated Program for Antimicrobial Resistance Surveillance to show a correlation between air temperature and precipitation, on one hand, and microbial food-borne contamination, on the other. Similar studies have used surveillance data to identify associations between enteric infections and temperature (Ravel et al., 2010; David et al., 2017). New opportunities to enhance existing surveillance systems exist. For example, there are opportunities to integrate climate variables into the FoodNet Canada Surveillance System that tracks enteric disease risks throughout the farm-to-fork continuum in regions of urban–rural interface (e.g., retail foods, farm, water) (PHAC, 2017). Nevertheless, challenges for surveillance remain. For example, the proportion of enteric infections attributable to food consumption versus water and other sources of infection remains unknown (Butler et al., 2016), and the true burden of food-borne illness is underestimated due to under-diagnosis and under-reporting (Harper et al., 2015c; Thomas et al., 2015).

The ability of surveillance systems to provide early warning of the emergence of new or existing climate-sensitive diseases needs to be further investigated and strengthened (Ford et al., 2014), particularly for high emissions scenarios (e.g., RCP 8.5) (Costello et al., 2009; Ebi et al., 2018) and for risks that may emerge from outside food systems (e.g., via trade) (Lake, 2017). Climate change could make current food-related surveillance systems inadequate, underpinning the importance of horizon scanning to anticipate new threats (Lake, 2017).

National household food insecurity data are collected in the Canadian Community Health Survey, so that temporal changes in the prevalence of household food insecurity can be detected. However, the survey's results provide an incomplete picture of the state of food security in Canada with each survey cycle, as some provinces and territories can opt out of its food security component, and several population groups, including First Nations living on reserves and those living in long-term care homes and prisons, are excluded (PROOF, 2018). Furthermore, the ability to examine fine-scale demographic, temporal, and spatial details with these data is limited (PROOF, 2018). Such data have not been used to examine the impacts of climate and climate change on food security in Canada (Ebi et al., 2017; Ford et al., 2019; Lam et al., 2019). Because the survey has limited ability to capture the multi-dimensional nature of food security among First Nations, Inuit, and Métis Peoples, alternative food security measurement approaches must be developed, rooted in cultural values and Indigenous knowledge, and focusing on consumption of traditional and retail foods and on the role of sharing networks in underpinning food access (Ready, 2016; Ford et al., 2019).

Existing surveillance systems are insufficient to detect the occurrence and spread of climate-related health risks for many Indigenous Peoples in Canada (Harper et al., 2015b; Sawatzky et al., 2018; Lam et al., 2019), thus increasing their vulnerability to future impacts (Ford et al., 2010; Harper et al., 2015a). Gaps in surveillance have been documented in Indigenous communities, and these gaps exist for a range of reasons, such as missing data, differing interactions with health care systems, and high costs of patient follow-up needed to provide data (Ford et al., 2010; Harper et al., 2011; Pardhan-Ali et al., 2012a; Pardhan-Ali et al., 2012b; Pardhan-Ali et al., 2013; Ford et al., 2014; Harper et al., 2015a; Harper et al., 2015b; Harper et al., 2015c). Indigenous knowledge is critical for robust climate change and health surveillance efforts (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Several studies demonstrate the effectiveness of Indigenous knowledge for community-based monitoring and surveillance systems to monitor and respond to climate-related changes in access to Indigenous land-based activities, species distribution, food safety, and associated health impacts (e.g., food security, nutrition, personal safety and injury, food-borne pathogens, and new and re-emerging infectious diseases) (Berner et al., 2016; Blangy et al., 2018; Sawatzky et al., 2018; Kipp et al., 2019; Lam et al., 2019).

Box 8.5 Adaptation actions to reduce emerging *V. parahaemolyticus* risks in oysters

The health risks from *V. parahaemolyticus* in oysters harvested in Canada are projected to increase due to climate change (see Box 8.3). Adaptation efforts are required to prevent these risks from increasing the burden of food-borne illness.

Improved ability to predict emerging risks from *V. parahaemolyticus* could be used for early warnings, to target the timing and location of public health interventions and to inform new health-related industry practices. For example, under a predicted strong El Niño–Southern Oscillation event, adaptation efforts could include adjustments in industry practices and regulatory policy, especially for seafood that is consumed raw, such as oysters. Other options include more stringent post-harvest temperature controls to limit pathogen growth. However, during a 2004 *V. parahaemolyticus* outbreak in Alaska, pathogen levels at harvest posed significant health risks, despite post-harvest controls (Martinez-Urtaza et al., 2010). *V. parahaemolyticus* levels at harvest were reduced by an order of magnitude the following year by adopting a new practice in which oysters were held 15 to 30 m deeper in the water and, therefore, at colder temperatures, for one month before harvest (Martinez-Urtaza et al., 2010). Alternatively, post-harvest processes such as mild heat, high hydrostatic pressure, and freezing can reduce levels of *V. parahaemolyticus* and other pathogens, such as *V. cholerae* and *V. vulnificus*. These processes generally retain the raw oysters' sensory characteristics that consumers prefer. As risks to health increase with a warming climate, these adaptation options provide opportunities to protect Canadians.

8.6.1.4 Risk Communication and Education

Awareness of climate change risks has a powerful influence on the initiation and development of adaptation programs and the adoption of adaptive behaviours (Grothmann & Patt, 2005; Moser, 2014; Ford & King, 2015). There are a number of examples in which health authorities have undertaken activities to increase education and awareness of climate change impacts on food and to promote individual behavioural change. In Quebec, the *Mon climat, ma santé* website was designed to increase public awareness of climate-related health impacts. The website provides an introduction to the concept of food insecurity and discusses various ways that climate change will affect food production and consumption in Canada and globally. The website promotes food security in a changing climate, emphasizing buying local foods, community gardening, and holding events such as cooking workshops to teach citizens how to reduce food waste (INSPQ, n.d.). At a city level, in Montréal, a 2017 pilot project in the neighbourhood of Notre-Dame-de-Grâce aimed to improve emergency preparedness through community resilience workshops. Citizens were encouraged to assemble 72-hour emergency kits that included recipes suited to emergency situations and food (City of Montreal, 2018). Additionally, the federal government has funded many projects through First Nations Adapt, Climate Change Preparedness in the North, and HealthADAPT programs that include risk communication and community-based education. The Young Hunters Program in Arviat, Nunavut, for example, uses SmartIce technology to monitor sea ice thickness and keep the community informed about travel conditions. By including youth in data collection, young community members simultaneously learn about sea ice and wildlife safety. The First Nation of Nacho Nyak Dun in Yukon provides information to the community on climate change and food security by conducting knowledge-gathering activities, and then developing and translating information into the Northern Tutchone language.

8.6.2 Vulnerability-Centred Adaptations

8.6.2.1 Tackling the Root Causes of Vulnerability

The people who are disproportionately affected by climate change impacts on food security and food safety are those who are socio-economically disadvantaged and who already experience high burdens of ill health, such as people living on a low income, seniors, members of racialized communities, households headed by single women, and persons with disabilities (Smith et al., 2014; FAO, 2016). Adaptation actions that address societal conditions underlying climate-health vulnerability can enhance food security and food safety, as well as contributing to health equity and overall community resilience (see Chapter 9: Climate Change and Health Equity). For instance, for Indigenous Peoples, this includes supporting and promoting Indigenous food sovereignty (Box 8.6). Opportunities for action discussed in existing literature are diverse and commonly examined in the context of Indigenous food systems; they include investing in social safety nets to respond to food emergencies (e.g., soup kitchens), poverty alleviation, truth and reconciliation, education, inclusive governance, and cultural promotion (Ford et al., 2013; Skinner et al., 2013; Fillion et al., 2014; Ford et al., 2014; Organ et al., 2014; Ford et al., 2016; Rosol et al., 2016). These actions have multiple health co-benefits and can strengthen important determinants of health, including food security.

Box 8.6 Indigenous food sovereignty as a climate change solution

The Indigenous food sovereignty movement is rising in response to the imposition of Western industrial food systems, as Indigenous nations seek to reclaim their well-being through the revitalization of traditional food systems (Whyte, 2016; Delormier et al., 2017). Indigenous food sovereignty connotes an alternative food system that involves Indigenous knowledge and mutually beneficial relationships to the land, contrasting with many large-scale mainstream food systems characterized by industrialism, capitalism, and globalism. Indigenous food sovereignty seeks the integration of political, social, economic, ecological, and spiritual aspects of food. It asserts that Indigenous communities have the right to preserve their cultural traditions and practices surrounding the production, harvesting, and sharing of food (Lemke & Delormier, 2017). Indigenous food sovereignty conveys a "restorative framework for health and community development," as well as healing relationships with each other, the land, animals, and plants (Morrison, 2011). Four central principles have been associated with Indigenous food sovereignty (Morrison, 2011):

- Food is sacred and cannot be constrained by colonial laws and policies; its value is instead upheld by acting on long-standing sacred responsibilities to land, animals, and plants.
- Participation in the day-to-day practice of nurturing healthy relationships with land and each other is essential to maintaining Indigenous food sovereignty.
- Self-determination — the freedom to make decisions regarding food to support healthy people and communities — is critical.
- There is a need for broad policy reform to reconcile Indigenous food systems with colonial laws and policies.

Addressing Indigenous food sovereignty, as opposed to security, is a challenging task. It involves the analysis of the root causes of health disparities experienced by Indigenous Peoples as they relate to food systems, including the imposition of colonial food systems. The need for the revitalization of traditional food practices is a vital component of food sovereignty and necessitates the recognition of Aboriginal and treaty rights (Government of Canada, 2020) so that access to traditional lands may be secured.

In Indigenous systems, food is conceptualized as a gift, a source of life. It plays a central role in ceremonies, identity, and culture, and is an integral component of the web of relationships between people and the land (Whyte, 2016). Access to traditional foods is an essential element of Indigenous culture, language, and well-being at the individual and community level. Such access depends on the maintenance of both physical and spiritual relationships to the land.

The linkage between Indigenous knowledge and food is a critical consideration when examining food security in the context of climate change. Knowledge of food systems is taught, and relationships with food are perpetuated, through social engagements within and among families, communities, and other societies. When the Western agri-food system model supplanted the traditional food system, the transmission of Indigenous knowledge was greatly diminished (Grey & Patel, 2015; Kermoal & Altamirano-Jiménez, 2016). Diets are healthier in those areas where traditional foods are eaten more often (Johnson-Down & Egeland, 2010; Gagné et al., 2012; Chan et al., 2019). Furthermore, there is a gendered component to the impact of food insecurity. Women traditionally hold specialized knowledge about food systems, including its production, harvesting, preparation, and safety, and actively promote the nutritional and medicinal properties of food, as well as contributing to the stewardship of the land (Lemke & Delormier, 2017).

Mainstreaming or integrating climate change considerations and information on risks to food security and food safety into existing policies and programs can also help to address underlying causes of vulnerability. Some jurisdictions are taking such actions already. The Government of Nunavut's Food Security Strategy and Action Plan, developed in collaboration with the Nunavut Tunngavik Inc., Inuit organizations, non-governmental organizations, and the private sector, accounts for climate change impacts on food accessibility and promotes food-related skills important for adaptation (NFSC, 2014). Similarly, other territorial adaptation plans emphasize the importance of supporting health and wellness activities to build community resilience to multiple stresses, including climate change. Other measures to address food insecurity focus on increasing the self-sufficiency of local and regional food systems, which, in turn, can increase climate resilience (Sonnino, 2016; Dorward et al., 2017). Calgary's Food System Assessment and Action Plan incorporates local climate projections, addresses adaptation challenges and opportunities throughout food systems, and showcases local examples of urban farming (City of Calgary, 2012). Municipalities across Canada are increasingly encouraging the creation of community gardens, permitting the keeping of chickens within city boundaries, supporting farmer's markets and community agriculture programs, and growing urban food forests.[3] Such actions can contribute to community climate resilience and have many health co-benefits.

8.6.2.2 Strengthening Health Systems

Strengthening health systems to improve the management of current and future risks from climate change is central to adaptation (Ford et al., 2014; Watts et al., 2015) (see Chapter 10: Adaptation and Health System Resilience). Public health authorities play a critical role in maintaining health and well-being, through health protection, promotion, screening, and surveillance related to food safety (Charron et al., 2008). There is limited knowledge of the effectiveness of current measures to reduce health risks from the potential food-related impacts of climate change (Yusa et al., 2015).

Given the interdependent relationships among food systems, health, and climate change, food can be an important intervention point for climate action and health equity within the health care system. For example, Nourish: The Future of Food in Health Care, a collaborative initiative led by the McConnell Foundation with partners across Canada, has worked to empower health care leaders to take greater actions on climate change and health equity issues through interventions with food (Nourish, n.d.).The Nourish Innovator Program, which ran from December 2016 to May 2019, brought innovators from 25 Canadian hospitals and health authorities together to collaborate on a series of projects that leveraged the power of food to achieve impact in three cross-cutting areas: climate, equity, and community well-being. National collaborative projects

3 Located in urban areas and mimicking a natural ecosystem, urban food forests consist of perennial trees and edible plants (Clark & Nicholas, 2012).

included initiatives related to traditional and cultural food programs, sustainable menus, value-based and local food procurement in health care, and measuring patient food experiences.

8.6.3 Adaptation Progress and Future Challenges

Adaptation efforts are underway at federal, provincial, territorial, municipal, community, household, and individual levels to respond to the food-related impacts of climate change, although analysis in this chapter indicates more action is needed. Continued monitoring and evaluation of adaptation will be essential for tracking progress in responding to risks and learning from actions, necessitating the development of new methods, approaches, and datasets (Ford et al., 2016; ECCC, 2018; Berrang-Ford et al., 2019; Lesnikowski et al., 2019).

Barriers impeding efforts to reduce risks to health from climate change impacts on food security and safety include uncertainty of climate change impacts; lack of financial resources; insufficient social capital; prioritization of more immediate public health challenges; fragmented institutional arrangements; and jurisdictional challenges (Huang et al., 2011; Clarke & Berry, 2012; Paterson et al., 2012; Yusa et al., 2015; Roser-Renouf et al., 2016; Austin et al., 2018; Austin et al., 2019). There are also potential limits to adaptation, although little scholarship has assessed these limits in a climate–health context in general (Ebi & Hess, 2017; de Coninck et al., 2018) or for food security and food safety in particular. Associated debates around loss, damage, and compensation are relevant in Canada, particularly for Indigenous Peoples, who face an unequal and inequitable burden of impact, but have not yet been examined (Ford, 2009; Landauer & Juhola, 2019).

Another challenge to adaptation is that, in climate change policy planning, food security tends to be framed as primarily an economic and/or GHG emissions mitigation issue, rather than as a social, cultural, or public health challenge that needs to be addressed. Food policies and programs in response to climate change are, therefore, being developed primarily under sustainability, mitigation, or resilience policy initiatives and often lack strong linkages to public health issues and concerns.

8.7 Knowledge Gaps and Recommendations

8.7.1 Food Security

The existing literature on climate change and food security generally focuses on food availability, and research generally places a disproportionately large emphasis on climate change impacts on food production, rather than other components of the food system (Nelson et al., 2016). As a result, there is limited understanding of the impacts climate change will have on non-production components of food systems (i.e., food processing, distribution, preparation, and consumption) (Porter et al., 2014), and on human health. Further, studies have tended to concentrate on single-factor changes that might affect food systems, rather than delving into the more complex and multi-layered features of food security that require integration of environmental, political, economic, and social factors. As a result, a number of knowledge gaps exist, particularly regarding food system components most vulnerable to climate change, the consequences for human health, and the most effective adaptation strategies (Schnitter & Berry, 2019).

The severity and significance of climate change effects on food security, as well as the capacity to adapt, will vary across the country. Although a number of studies have explored climate change impacts on food security in Northern Canada, knowledge gaps persist in that region. Further, improving understanding of the main risks and vulnerabilities facing populations in regions south of 60 degrees north latitude, including rural and remote communities as well as urban centres, requires targeted analysis. Regional and local food system assessments and analyses are needed to identify unique vulnerabilities and inform appropriate adaptation strategies, with particular consideration for individuals who will face disproportionate impacts and may already face nutritional risk and food insecurity (e.g., low-income households, Indigenous Peoples, households headed by single women).

Given the integrated nature of food systems, disruption of one component of the food system can disrupt critical operations of other components. Consequently, future research examining the climate change, food security, and human health nexus from a food system perspective would help identify critical vulnerabilities and points of adaptation intervention. A food system perspective also encourages the collaboration of all food system actors. Indeed, many adaptation actions that contribute to a resilient food system fall outside of the jurisdiction of the health sector and will require a multi-sectoral response (Schnitter & Berry, 2019).

To understand risks to food security from climate change, specific knowledge is needed, including research to:

- identify processing and distribution facilities in Canada that are most vulnerable to disruption from extreme weather events and prioritize the most vulnerable sites for resilience-building activities;
- map food transportation and distribution networks across Canada and identify important facilities to assess climate change risks and implement adaptation actions;
- investigate how food distribution systems might adapt to short-term disruptions and longer-term challenges caused by climate change;

- examine climate change impacts on nutrition in a Canadian context, including examining the impact elevated CO_2 concentrations will have on nutritional content of key crops and studying potential climate-related diet shifts and implications for Canadians, and analyzing potential food substitutions and implications for dietary guidelines;
- evaluate and monitor the effectiveness of current measures to reduce health risks from impacts of climate change on food insecurity;
- enhance research and understanding of key factors that contribute to food insecurity, including analysis of compounding, intersecting vulnerability factors and the impact climate change will have on this relationship; and
- increase research and understanding of the impacts climate change may have on food security specifically for First Nations, Inuit, and Métis peoples.

8.7.2 Food Safety

Several Canadian and international studies have used surveillance data to link climate variables and/or climate change to incidence of enteric diseases. Fewer studies have directly associated climate change with food safety by, for example, linking climate to the occurrence of pathogens in foods or to illness directly attributed to food consumption. It is difficult to estimate the precise effect of climate change on food safety, as many food-borne pathogens can also be acquired via contaminated water consumption, direct contact with animals, and human-to-human transmission. Enhanced and integrated monitoring and surveillance of animals, the environment (including water), and foods for pathogens would help to address important knowledge gaps. Several food safety surveillance systems are established in Canada to monitor food-borne diseases; nevertheless, most of these surveillance systems do not currently include climate variables. An opportunity exists to integrate climate variables into food safety surveillance systems to be able to monitor trends in climate-related food-borne illness.

Food safety-related issues are under-represented in the climate-health literature relative to other health indicators (Springmann et al., 2016). More studies are needed to project the impacts of climate change and adaptation measures on food safety in Canada. Risk modelling work conducted thus far indicates that food-borne disease risks are projected to increase with climate change for several combinations of foods, pathogens, and regions (Smith et al., 2015). These types of mathematical models can be populated with data from enhanced surveillance programs that include climate variables, as well as new primary research on the evidence for pathogen behaviours under simulated climate scenarios, to derive risk projections for more food safety issues. Diseases previously considered exotic or rare to Canada should be reconsidered in light of climate changes expected in Canada (Greer et al., 2008). Cross-disciplinary research using various methodological tools can provide useful insights and forecast disease transmission patterns under specific climatic conditions (Greer et al., 2008).

More research is also required to fully understand the impact of climate change and variability on the fate of chemical contaminants in the environment. While ocean warming and acidification will affect the bioaccumulation of contaminants in aquatic species and the structure and distribution of food webs, additional research is needed to understand the changing physical biochemical basis and the changing geographical distribution of aquatic species. Furthermore, to address climate-related environmental changes, integrated surveillance of water, soils, and foods for contaminants and chemical residues; crops for pesticide residues; animal products for veterinary residues; and emerging animal and human diseases is essential (WHO, 2008; Tirado et al., 2010). The data generated from this research can be used to identify emerging problems and food contamination trends and to contribute to risk assessments (Moulton & Schramm, 2017).

To understand risks to food safety from climate change, specific knowledge is needed, including research to:

- regularly review Canadian food inspection regulations and policies to ensure that they are robust enough to cover emerging food safety issues, both in Canada and in countries from which food is imported;
- investigate how climate change adaptation measures may affect food safety and human health — for example, examine potential food safety issues and associated adaptations related to traditional preparation and storage methods used by Indigenous Peoples and how climate change may influence these practices;
- enhance and expand existing food safety surveillance systems to include climate variables and to integrate monitoring of animals and the environment;
- enhance models and derive risk projections for food-borne illnesses in the context of climate change; and
- examine the impact of climate change on the fate of chemical contaminants in the environment.

8.8 Conclusions

This chapter explores the linkages among climate change, food systems, and human health, as well as how society can adapt to reduce potential health risks in Canada. Several important themes have emerged and reveal the various challenges and opportunities for addressing the impacts of climate change on food security and food safety for human health outcomes in Canada, including:

- the pervasiveness of climate change impacts on all food system components, throughout the production, processing, distribution, preparation, and consumption phases, and the subsequent challenges for human health;
- the need to consider both the direct and indirect climate-related impacts on food systems, food security, and food safety on human health;
- the vulnerability of specific populations (e.g., low-income communities, Indigenous Peoples, marginalized communities, children, and older adults) to risks associated with food safety and food security in the context of climate change;
- the importance of acknowledging the multiple and intersecting ways environmental, social, political, and economic determinants affect health in the context of food systems, food security, and food safety;
- the globalization of food systems, causing climate change impacts on food security and health to be experienced at both a global and local level; and
- the variability of food safety and food security risks to health by region, and the resulting need for adaptation models to account for unique place-based experiences (driven by consumption patterns, cultural norms, preference, climate, etc.), while accounting for socio-economic barriers and other social determinants of health in order to build capacity for resilience.

As challenges to food systems, food security, and food safety present potentially severe threats to human health in and outside of Canada (Confalonieri et al., 2007; Friel et al., 2011; Bradbear & Friel, 2013; Porter et al., 2014; Bowen & Ebi, 2015; Wang & Horton, 2015; Springmann et al., 2016), it is crucial to gain greater understanding of risks from climate change and of opportunities to protect people. Despite existing knowledge gaps, efforts to address the health risks associated with climate change impacts on food systems are already underway in Canada. Evaluating and monitoring the effectiveness of these activities can elucidate important learnings and contribute to the implementation of actions across the country. Collaboration, spanning across all sectors and levels of government, will be critical to adapt effectively to climate change impacts on food security and safety in Canada.

8.9 References

Aberman, N.-L., & Tirado, C. (2014). Impacts of climate change on food utilization. In B. Freedman (Ed.), *Global Environmental Change* (pp. 717–724). Dordrecht, Netherlands: Springer. <https://doi.org/10.1007/978-94-007-5784-4_124>

Agency for Toxic Substances & Disease Registry (ATSDR). (1999). *Toxicological Profile for Mercury.* Retrieved from <https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=115&tid=24>

Agency for Toxic Substances & Disease Registry (ATSDR). (2020). *ToxGuide for lead.* Retrieved from <https://www.atsdr.cdc.gov/toxguides/toxguide-13.pdf>

Agriculture and Agri-Food Canada (AAFC). (2015). *Impact of climate change on Canadian agriculture.*

Agunos, A., Waddell, L., Léger, D., & Taboada, E. (2014). A systematic review characterizing on-farm sources of Campylobacter spp. for broiler chickens. *PLoS ONE*, 9(8), e104905. <https://doi.org/10.1371/journal.pone.0104905>

Alava, J. J., Cheung, W. W. L., Ross, P. S., & Sumaila, U. R. (2017). Climate change-contaminant interactions in marine food webs: Toward a conceptual framework. *Global Change Biology*, *23*(10), 3984–4001. <https://doi.org/10.1111/gcb.13667>

Alava, J. J., Cisneros-Montemayor, A. M., Sumaila, U. R., & Cheung, W. W. L. (2018). Projected amplification of food web bioaccumulation of MeHg and PCBs under climate change in the Northeastern Pacific. *Scientific Reports*, *8*(1), 13460. https://doi.org/10.1038/s41598-018-31824-5

Al Nasir, F., & Batarseh, M. I. (2008). Agricultural reuse of reclaimed water and uptake of organic compounds: Pilot study at Mutah University wastewater treatment plant, Jordan. *Chemosphere*, *72*(8), 1203–1214. https://doi.org/https://doi.org/10.1016/j.chemosphere.2008.01.064

Anand, S. S., Hawkes, C., de Souza, R. J., Mente, A., Dehghan, M., Nugent, R., … Popkin, B. M. (2015). Food consumption and its impact on cardiovascular disease: importance of solutions focused on the globalized food system: a report from the workshop convened by the World Heart Federation. *Journal of the American College of Cardiology*, *66*(14), 1590–1614. <https://doi.org/10.1016/j.jacc.2015.07.050>

Anderson, D., Ford, J. D., & Way, R. G. (2018). The impacts of climate and social changes on cloudberry (bakeapple) picking: a case study from southeastern Labrador. *Human Ecology*, *46*(6), 849–863. <https://doi.org/https://dx.doi.org/10.1007/s10745-018-0038-3>

Arctic Monitoring and Assessment Programme (AMAP). (2015). *AMAP Assessment 2015: Human health in the Arctic*. Oslo, Norway. <https://doi.org/10.3402/ijch.v75.33949>

Armitage, J. M., Quinn, C. L., & Wania, F. (2011). Global climate change and contaminants—an overview of opportunities and priorities for modelling the potential implications for long-term human exposure to organic compounds in the Arctic. *Journal of Environmental Monitoring*, *13*(6), 1532–1546. <https://doi.org/10.1039/C1EM10131E>

Arnell, N. W., Brown, S., Gosling, S. N., Gottschalk, P., Hinkel, J., Huntingford, C., … Zelazowski, P. (2016). The impacts of climate change across the globe: A multi-sectoral assessment. *Climatic Change*, *134*, 457–474. <https://doi.org/10.1007/s10584-014-1281-2>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., & Ross, N. A. (2019). Enabling local public health adaptation to climate change. *Social Science & Medicine*, *220*, 236–244. <https://doi.org/10.1016/j.socscimed.2018.11.002>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., Tosun, J., & Ross, N. A. (2018). Intergovernmental relations for public health adaptation to climate change in the federalist states of Canada and Germany. *Global Environmental Change*, *52*, 1–22. <https://doi.org/10.1016/j.gloenvcha.2018.07.010>

Bacon, S., Campbell, N., Raine, K., Tsuyuki, R., Khan, N., Arango, M., & Kaczorowski, J. (2019). Canada's new Healthy Eating Strategy: Implications for health care professionals and a call to action. *Canadian Pharmacists Journal/Revue des Pharmaciens du Canada*, *152*(3), 151–157. <https://doi.org/10.14288/hfjc.v12i1.275>

Baker-Austin, C., Trinanes, J., Gonzalez-Escalona, N., & Martinez-Urtaza, J. (2017). Non-Cholera Vibrios: The Microbial Barometer of Climate Change. *Trends in microbiology*, *25*(1), 76–84. https://doi.org/10.1016/j.tim.2016.09.008

Banerjee, S. K., Rutley, R., & Bussey, J. (2018). Diversity and dynamics of the Canadian coastal Vibrio community: an emerging trend detected in the temperate regions. *Journal of Bacteriology, 200*(15), e00787-17. https://doi.org/10.1128/jb.00787-17

Batal, M., Johnson-Down, L., Moubarac, J. C., Ing, A., Fediuk, K., Sadik, T., … Willows, N. (2017). Sociodemographic associations of the dietary proportion of ultra-processed foods in First Nations peoples in the Canadian provinces of British Columbia, Manitoba, Alberta and Ontario. *International Journal of Food Sciences and Nutrition*, *69*(6), 753–761. <https://doi.org/10.1080/09637486.2017.1412405>

Bates, P. (2007). Inuit and scientific philosophies about planning, prediction, and uncertainty. *Arctic Anthropology*, *44*(2), 87–100. <https://doi.org/10.1353/arc.2011.0065>

Beaudin-Reimer, B. (2020). Perspectives from Métis Harvesters in Manitoba on Concerns and Challenges to Sustaining Traditional Harvesting Practices and Knowledge: A Distinctions-Based Approach to Indigenous Food Sovereignty. In P. Settee, & S. Shukla (Eds.), *Indigenous Food Systems: Concepts, Cases, and Conversations* (pp. 229). Toronto, ON: Canadian Scholars.

Berner, J., Brubaker, M., Revitch, B., Kreummel, E., Tcheripanoff, M., & Bell, J. (2016). Adaptation in Arctic circumpolar communities: food and water security in a changing climate. *International Journal of Circumpolar Health*, *75*(1), 33820. <https://doi.org/10.3402/ijch.v75.33820>

Berrang-Ford, L., Biesbroek, R., Ford, J. D., Lesnikowski, A., Tanabe, A., Wang, F. M., … Heymann, S. J. (2019). Tracking global climate change adaptation among governments. *Nature Climate Change*, *9*, 440–449.

Berry, P., Clarke, K., Fleury, M. D., & Parker, S. (2014a). Human health. In F.J. Warren & D.S. Lemmen (Eds.), *Canada in a changing climate: sector perspectives on impacts and adaptation* (pp. 191–232). Ottawa, ON: Government of Canada.

Berry, P., Enright, P. M., Shumake-Guillemot, J., Villalobos Prats, E., & Campbell-Lendrum, D. (2018). Assessing health vulnerabilities and adaptation to climate change: a review of international progress. *International Journal of Environmental Research and Public Health*, *15*(12), 2626. <https://doi.org/10.3390/ijerph15122626>

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of vulnerability to the health impacts of climate change in Middlesex-London*. London, ON.

Biehl, E., Buzogany, S., Baja, K., & Neff, R. (2018). Planning for a resilient urban food system: a case study from Baltimore City, Maryland. *Journal of Agriculture, Food Systems, and Community Development*, *8*(B), 39–53. <https://doi.org/10.5304/jafscd.2018.08B.008>

Bishop-Williams, K. E., Berke, O., Pearl, D. L., Hand, K., & Kelton, D. F. (2015). Heat stress related dairy cow mortality during heat waves and control periods in rural Southern Ontario from 2010–2012. *BMC Veterinary Research*, *11*(1), 291. <https://doi.org/10.1186/s12917-015-0607-2>

Blangy, S., Bernier, M., Bhiry, N., Jean-Pierre, D., Aenishaenslin, C., Bastian, S., … Rousse, D. (2018). OHMi-Nunavik: A multi-thematic and cross-cultural research program studying the cumulative effects of climate and socio-economic changes on Inuit communities. *Ecoscience*, *25*(4), 311–324. <https://doi.org/10.1080/11956860.2018.1542783>

Boeckman, C., & Bidwell, J. (2006). The effects of temperature, suspended solids, and organic carbon on copper toxicity to two aquatic invertebrates. *Water, Air, & Soil Pollution*, *171*(1–4), 185–202. <https://doi.org/10.1007/s11270-005-9036-3>

Bogdal, C., Schmid, P., Zennegg, M., Anselmetti, F. S., Scheringer, M., & Hungerbuhler, K. (2009). Blast from the past: melting glaciers as a relevant source for persistent organic pollutants. *Environmental Science & Technology*, *43*(21), 8173–8177. <https://doi.org/10.1021/es901628x>

Booth, S., & Zeller, D. (2005). Mercury, food webs, and marine mammals: implications of diet and climate change for human health. *Environmental Health Perspectives*, *113*(5), 521–526. <https://doi.org/10.1289/ehp.7603>

Boucher, O., Jacobson, S. W., Plusquellec, P., Dewailly, E., Ayotte, P., Forget-Dubois, N., Jacobson, J. L., & Muckle, G. (2012). Prenatal methylmercury, postnatal lead exposure, and evidence of attention deficit/hyperactivity disorder among Inuit children in Arctic Québec. *Environmental health perspectives*, *120*(10), 1456–1461. <https://doi.org/10.1289/ehp.1204976>

Boulanger-Lapointe, N. N., Gerin-Lajoie, J., Collier, L. S., Desrosiers, S., Spiech, C., Henry, G. H. R., … Cuerrier, A. (2019). Berry plants and berry picking in Inuit Nunangat: Traditions in a changing socio-ecological landscape. *Human Ecology*, *47*(1), 81–93. <https://doi.org/10.1007/s10745-018-0044-5>

Bowen, K. J., & Ebi, K. L. (2015). Governing the health risks of climate change: towards multi-sector responses. *Current Opinion in Environmental Sustainability*, *12*, 80–85. <https://doi.org/10.1016/j.cosust.2014.12.001>

Bowron, B., & Davidson, G. (2011). *Climate change adaptation planning: A Nunavut toolkit*. Ottawa, ON. Retrieved from <https://www.climatechangenunavut.ca/sites/default/files/nunavut_toolkit_final_2011_0.pdf>

Boxall, A. B. A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P. D., … Williams, R. J. (2009). Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. *Environmental Health Perspectives*, *117*(4), 508–514. <https://doi.org/10.1289/ehp.0800084>

Bradbear, C., & Friel, S. (2013). Integrating climate change, food prices and population health. *Food Policy*, *43*, 56–66. <https://doi.org/10.1016/J.FOODPOL.2013.08.007>

Breewood, H. (2018). *What is the nutrition transition? Foodsource: building blocks*. Retrieved from <https://www.tabledebates.org/building-blocks/what-nutrition-transition>

Broberg, C. A., Calder, T. J., & Orth, K. (2011). *Vibrio parahaemolyticus* cell biology and pathogenicity determinants. *Microbes and Infection*, *13*(12–13), 992–1001. <https://doi.org/10.1016/j.micinf.2011.06.013>

Brown, T. M., Macdonald, R. W., Muir, D., & Letcher, R. J. (2018). The distribution and trends of persistent organic pollutants and mercury in marine mammals from Canada's Eastern Arctic. *The Science of the Total Environment*, *618*, 500–517. <https://doi.org/10.1016/j.scitotenv.2017.11.052>

Brunn, A., Fisman, D. N., Sargeant, J. M., & Greer, A. L. (2019). The influence of climate and livestock reservoirs on human cases of Giardiasis. *EcoHealth, 16*(1), 116–127. <https://doi.org/10.1007/s10393-018-1385-7>

Buckman, A. H., Fisk, A. T., Parrott, J. L., Solomon, K. R., & Brown, S. B. (2007). PCBs can diminish the influence of temperature on thyroid indices in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology*, *84*(3), 366–378. <https://doi.org/https://doi.org/10.1016/j.aquatox.2007.06.016>

Bunce, A., Ford, J., Harper, S., Edge, V., Namanya, D. B., Berrang-Ford, L., … Lwasa, S. (2016). Vulnerability and adaptive capacity of Inuit women to climate change: a case study from Iqaluit, Nunavut. *Natural Hazards*, *83*(3), 1419–1441. <https://doi.org/10.1007/s11069-016-2398-6>

Buse, C. G. (2018). Why should public health agencies across Canada conduct climate change and health vulnerability assessments? *Canadian Journal of Public Health*, *109*(5–6), 782–785. <https://doi.org/10.17269/s41997-018-0118-6>

Bush, E., & Lemmen, D. S. (Eds.). (2019). *Canada's changing climate report*. Ottawa, ON: Environment and Climate Change Canada.

Butler, A. J., Pintar, K. D. M., & Thomas, M. K. (2016). Estimating the relative role of various subcategories of food, water, and animal contact transmission of 28 enteric diseases in Canada. *Foodborne Pathogens and Disease*, *13*(2), 57–64. <https://doi.org/10.1089/fpd.2015.1957>

Butler, C. (2014a). *Climate change and global health*. Oxsfordshire, United Kingdom: Centre for Agriculture and Bioscience International. <https://doi.org/10.1079/9781780642659.0011>

Butler, C. (2014b). Food and water and climate change. In B. Freedman (Ed.), *Global Environmental Change* (pp. 629-648). Springer.

Cabello, A., Espejo, R., & Romero, J. (2005). Tracing in oysters (*Tiostrea chilensis*) using a Green Fluorescent Protein tag. *Journal of Experimental Marine Biology and Ecology, 327*(2), 157–166. <https://doi.org/10.1016/j.jembe.2005.06.009>

Cameron, E., Mearns, R., & McGrath, J. T. (2015). Translating climate change: adaptation, resilience, and climate politics in Nunavut, Canada. *Annals of the Association of American Geographers*, *105*(2), 274–283. <https://doi.org/10.1080/00045608.2014.973006>

Campbell, I. D., Durant, D. G., Hunter, K. L., & Hyatt, K. D. (2014). Food production. In F. J. Warren & D. S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 99–134). Ottawa, ON: Natural Resources Canada.

Canadian Food Inspection Agency (CFIA). (2014). Food safety hazards. *Imported and Manufactured Food Program Inspection Manual*. Ottawa, ON.

Canadian Food Inspection Agency (CFIA). (2018). *Canadian Food Safety Information Network (CFSIN)*. Retrieved from <https://www.inspection.gc.ca/science-and-research/cfsin/eng/1525378586176/1525378959647>

Carrie, J., Wang, F., Sanei, H., Macdonald, R. W., Outridge, P. M., & Stern, G. A. (2010). Increasing contaminant burdens in an Arctic fish, Burbot (*Lota lota*), in a warming climate. *Environmental Science & Technology*, *44*(1), 316–322. <https://doi.org/10.1021/es902582y>

Challinor, A. J., Adger, W. N., & Benton, T. G. (2017). Climate risks across borders and scales. *Nature Climate Change*, (7), 621–623. <https://doi.org/10.1038/nclimate3380>

Chan, L., Batal, M., Sadik, T., Tikhonov, C., Schwartz, H., Fediuk, K., … Berti, P. (2019). *FNFNES Final Report for Eight Assembly of First Nations Regions: Draft Comprehensive Technical Report*. Ottawa, ON: Assembly of First Nations, University of Ottawa, & Université de Montréal.

Charlebois, S., McGuinty, E., Keselj, V., Music, J., Guisto, A., Kevany, K., … Moksyakov, A. (2020). Canada's *Food Price Report* 2020 (10th ed.). Dalhousie University, & University of Guelph. Retrieved from <https://www.foodincanada.com/wp-content/uploads/2019/12/Canada-Food-Price-Report-Eng-2020.pdf>

Charlebois, S., & Summan, A. (2015). A risk communication model for food regulatory agencies in modern society. *Trends in Food Science & Technology*, *45*(1), 153–165. <https://doi.org/10.1016/j.tifs.2015.05.004>

Charron, D., Fleury, M., Lindsay, L. R., Ogden, N., & Schuster, C. J. (2008). The impacts of climate change on water-, food-, vector and rodent-borne diseases. In J. Sèguin (Ed.), *Human health in a changing climate: A canadian assessment of vulnerabilities and adaptive capacity* (pp. 171–210). Ottawa, ON: Health Canada.

Chukmasov, P., Aksenov, A., Sorokina, T., Varakina, Y., Sobolev, N., & Nieboer, E. (2019). North Pacific Baleen Whales as a Potential Source of Persistent Organic Pollutants (POPs) in the Diet of the Indigenous Peoples of the Eastern Arctic Coasts. *Toxics*, *7*(4), 65. <https://doi.org/10.3390/toxics7040065>

Cidro, J., Martens, T. R., Zahayko, L., & Lawrence, H. P. (2018). First foods as Indigenous food sovereignty: Country foods and breastfeeding practices in a Manitoban First Nations community. *Canadian Food Studies/La Revue Canadienne Des Études Sur l'alimentation*, *5*(2), 25–43.

Cisneros-Montemayor, A. M., Pauly, D., Weatherdon, L. V., & Ota, Y. (2016). A global estimate of seafood consumption by coastal indigenous peoples. *PloS One*, *11*(12), e0166681.

City of Calgary. (2012). *Calgary Eats! A Food System Assessment and Action Plan for Calgary*. Calgary, AB.

City of Castlegar. (2010). *Adapting to climate change project summary report & action plan*. Castlegar, BC.

City of Montreal. (2015). *Climate change adaptation plan for the Montreal urban agglomeration 2015-2010: Adaptation measures*. Montreal, QC.

City of Surrey. (2013). *Community Climate Action Strategy*. Surrey, BC.

City of Toronto. (2019). *Toronto's first resilience strategy*. Toronto, ON.

City of Toronto Environment Office. (2008). *Ahead of the storm: Preparing Toronto for climate change*. Toronto, ON.

City of Windsor. (2012). *City of Windsor Climate Change Adaptation Plan*. Windsor, ON.

Clarke, K. L., & Berry, P. (2012). From theory to practice: A Canadian case study of the utility of climate change adaptation frameworks to address health impacts. *International Journal of Public Health*, *57*, 167–174. <https://doi.org/10.1007/s00038-011-0292-2>

Collings, P., Marten, M. G., Pearce, T., & Young, A. G. (2016). Country food sharing networks, household structure, and implications for understanding food insecurity in Arctic Canada. *Ecology of Food and Nutrition*, *55*(1), 30–49. <https://doi.org/10.1080/03670244.2015.1072812>

Comeau, A. M., & Suttle, C. A. (2007). Distribution, genetic richness and phage sensitivity of *Vibrio spp.* from coastal British Columbia. *Environmental Microbiology, 9*(7), 1790–1800. <https://doi.org/10.1111/j.1462- 2920.2007.01299.x>

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K. L., Hauengue, M., Kovats, R.., … Woodward, A. (2007). Human Health. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 391–431). Cambridge, United Kingdom: Cambridge University Press.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., … Patterson, C. (2009). Managing the health effects of climate change. *The Lancet*, *373*, 1693. <https://doi.org/10.1016/S0140-6736(09)60935-1>

Coulombe, G., Catford, A., Martinez-Perez, A., & Buenaventura, E. (2020). Outbreaks of *Escherichia coli* O157:H7 infections linked to romaine lettuce in Canada from 2008 to 2018: An analysis of food safety context. *Journal of Food Protection, 83*(8), 1444–1462. <https://doi.org/10.4315/JFP-20-029>

Council of Canadian Academies (CCA). (2014). *Aboriginal food security in Northern Canada: an assessment of the state of knowledge*. Ottawa, ON.

Council of Canadian Academies (CCA). (2019). *Canada's top climate change risks: the expert panel on climate change risks and adaptation potential*. Ottawa, ON.

Cousins, M., Sargeant, J. M., Fisman, D., & Greer, A. L. (2019). Modelling the transmission dynamics of Campylobacter in Ontario, Canada, assuming houseflies, *Musca domestica*, are a mechanical vector of disease transmission. *Royal Society Open Science*, *6*(2), 181394. <https://doi.org/10.1098/rsos.181394>

Crown-Indigenous Relations and Northern Affiars Camada (CIRNAC). (2018). *Climate change preparedness in the North program*. Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1481305554936/1594738066665>

Crown-Indigenous Relations and Northern Affiars Camada (CIRNAC). (2019). *First Nation adapt program.* Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1481305681144/1594738692193>

David, J. M., Pollari, F., Pintar, K. D. M., Nesbitt, A., Butler, A. J., & Ravel, A. (2017). Do contamination of and exposure to chicken meat and water drive the temporal dynamics of Campylobacter cases? *Epidemiology and Infection*, *145*(15), 3191–3203. <https://doi.org/10.1017/S0950268817002199>

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., … Sugiyama, T. (2018). Strengthening and Implementing the Global Response. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield (Eds.), *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (p. 132). Cambridge, United Kingdom: Cambridge University Press.

Delcour, I., Spanoghe, P., & Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. *Food Research International*, *68*, 7–15. <https://doi.org/https://doi.org/10.1016/j.foodres.2014.09.030>

Delormier, T., Horn-Miller, K., McComber, A. M., & Marquis, K. (2017). Reclaiming food security in the Mohawk community of Kahnawà:ke through Haudenosaunee responsibilities. *Maternal & Child Nutrition*, *13*(S3), e12556. <https://doi.org/10.1111/mcn.12556>

Desmarais, A. A., & Wittman, H. (2014). Farmers, foodies and First Nations: getting to food sovereignty in Canada. *Journal of Peasant Studies*, *41*(6), 1153–1173. <https://doi.org/10.1080/03066150.2013.876623>

Dewailly, É., Ayotte, P., Bruneau, S., Lebel, G., Levallois, P., & Weber, J. P. (2000). Exposure of the Inuit population of Nunavik (Arctic Québec) to lead and mercury. *Archives of Environmental Health: An International Journal*, *56*(4), 350–357. <https://doi.org/10.1080/00039890109604467>

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health*, *109*(3), 327–337. <https://doi.org/10.17269/s41997-018-0070-5>

Dorward, C., Smukler, S. M., & Mullinix, K. (2017). A novel methodology to assess land-based food self-reliance in the Southwest British Columbia bioregion. *Renewable Agriculture and Food Systems*, *32*(2), 112–130. <https://doi.org/10.1017/S1742170516000053>

Duarte, S. C., Pena, A., & Lino, C. M. (2010). A review on ochratoxin A occurrence and effects of processing of cereal and cereal derived food products. *Food Microbiology*, 27(2), 187–198. <https://doi.org/10.1016/j.fm.2009.11.016>

Dupuis, J., & Biesbroek, R. (2013). Comparing apples and oranges: The dependent variable problem in comparing and evaluating climate change adaptation policies. *Global Environmental Change*, *23*(6), 1476–1487. <https://doi.org/10.1016/j.gloenvcha.2013.07.022>

Eagles-Smith, C. A., Wiener, J. G., Eckley, C. S., Willacker, J. J., Evers, D. C., Marvin-dipasquale, M., … Ackerman, J. T. (2016). Mercury in western North America: A synthesis of environmental contamination, fluxes, bioaccumulation, and risk to fish and wildlife. *Science of the Total Environment*, *568*, 1213–1226. <https://doi.org/10.1016/j.scitotenv.2016.05.094>

Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, S., … Tubiello, F. (2007). Food, fibre and forest products. In M. Parry, O. Canziani, J. Palutikof, P. van der Linden, & C. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 273–313). Cambridge, United Kingdom: Cambridge University Press.

Ebi, K. L. (2009). Public health responses to the risks of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine*, *51*(1), 4–12. <https://doi.org/10.1097/JOM.0b013e31816fd67b>

Ebi, K. L., Berry, P., Hayes, K., Boyer, C., Sellers, S., Enright, P. M., & Hess, J. J. (2018). Stress testing the capacity of health systems to manage climate change-related shocks and stresses. *International Journal of Environmental Research and Public Health*, *15*(11), 2370. <https://doi.org/10.3390/ijerph15112370>

Ebi, K. L., & Hess, J. J. (2017). The past and future in understanding the health risks of and responses to climate variability and change. *International Journal of Biometeorology*, *61*(S1), 71–80. <https://doi.org/10.1007/s00484-017-1406-1>

Ebi, K. L., Ogden, N. H., Semenza, J. C., & Woodward, A. (2017). Detecting and attributing health burdens to climate change. *Environmental Health Perspectives*, *125*(8), 085004. <https://doi.org/10.1289/EHP1509>

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine*, *35*(5), 501–507. <https://doi.org/10.1016/j.amepre.2008.08.018>

Edwards, F., Dixon, J., Friel, S., Hall, G., Larsen, K., Lockie, S., … Hattersley, L. (2011). Climate change adaptation at the intersection of food and health. *Asia Pacific Journal of Public Health*, *23*(2), 91S-104S. <https://doi.org/10.1177/1010539510392361>

Egeland, G. M. (2010). *Inuit Health Survey 2007-2008*. Montreal, QC. Retrieved from <https://www.mcgill.ca/cine/files/cine/adult_report_nunavut.pdf>

Environment and Climate Change Canada (ECCC). (2017). *High and dry in the East.*

Environment and Climate Chance Canada (ECCC). (2018). *Canadian centre for climate modelling and analysis*. Retrieved from <http://climate-modelling.canada.ca/data/data.shtml>

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*(1), 234–245. <https://doi.org/10.1016/j.gloenvcha.2007.09.002>

European Food Safety Authority (EFSA), Maggiore, A., Afonso, A., Barrucci, F., & Sanctis, G. D. (2020). Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality. *EFSA Supporting Publications*, *17*(6), 1881E. doi:10.2903/sp.efsa.2020.EN-1881

Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security*, *18*, 12–19. <https://doi.org/10.1016/J.GFS.2018.06.001>

Ferguson, A., Penney, R., & Solo-Gabriele, H. (2017). A review of the field on children's exposure to environmental contaminants: a risk assessment approach. *International Journal of Environmental Research and Public Health*, *14*(3), 265. <https://doi.org/10.3390/ijerph14030265>

Fillion, M., Laird, B., Douglas, V., Van Pelt, L., Archie, D., & Chan, H. M. (2014). Development of a strategic plan for food security and safety in the Inuvialuit settlement region, Canada. *International Journal of Circumpolar Health*, *73*(1), 25091. <https://doi.org/10.3402/ijch.v73.25091>

First Nations Information Governance centre (FNIGC). (2018). *National Report of the First Nations Regional Health Survey Phase 3: Volume 2*. Ottawa, ON.

Fleury, M., Charron, D. F., Holt, J. D., Allen, O. B., & Maarouf, A. R. (2006). A time series analysis of the relationship of ambient temperature and common bacterial enteric infections in two Canadian provinces. *International Journal of Biometeorology*, *50*(6), 385–391. <https://doi.org/10.1007/s00484-006-0028-9>

Flynn, M., Ford, J. D., Pearce, T., Harper, S. L., & Team, I. R. (2018). Participatory scenario planning and climate change impacts, adaptation and vulnerability research in the Arctic. *Environmental Science & Policy*, *79*, 45–53. <https://doi.org/10.1016/j.envsci.2017.10.012>

Food and Agriculture Organization of the United Nations (FAO). (1996). Rome declaration on world food security and World Food Summit Plan of Action. In *World Food Summit* (pp. 1–25). <https://doi.org/10.1163/ilwo-iiin2>

Food and Agriculture Organization of the United Nations (FAO). (2008). *Climate change and food security: A framework document*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). (2015). *Climate change and food systems: Global assessments and implications for food security and trade*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). (2016). *Climate change and food security: Risks and responses*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO), International Fund for Agriculture Development (IFAD), United Nations Children's Fund (UNICEF), World Food Programme (WFP), & World Health Organization (WHO). (2018). *The state of food security and nutrition in the world: Building climate resilience for food security and nutrition*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO), & World Health Organization (WHO). (2011). *Risk assessment of* Vibrio parahaemolyticus *in seafood: interpretive summary and technical report*. Rome, Italy.

Food and Drug Administration (FDA). (2005). *Quantitative risk assessment on the public health impact of pathogenic* Vibrio parahaemolyticus *in raw oysters*. Retrieved from <https://www.fda.gov/food/cfsan-risk-safety-assessments/quantitative-risk-assessment-public-health-impact-pathogenic-vibrio-parahaemolyticus-raw-oysters>

Ford, J. D. (2008). Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: a case study from Igloolik, Nunavut. *Regional Environmental Change*, *9*, 83–100. <https://doi.org/10.1007/s10113-008-0060-x>

Ford, J. D. (2009). Dangerous climate change and the importance of adaptation for the Arctic's Inuit population. *Environmental Research Letters*, *4*(2), 024006. <https://doi.org/10.1088/1748-9326/4/2/024006>

Ford, J. D., & Beaumier, M. (2011). Feeding the family during times of stress: experience and determinants of food insecurity in an Inuit community. *The Geographical Journal*, *177*(1), 44–61. <https://doi.org/http://dx.doi.org/10.1111/j.1475-4959.2010.00374.x>

Ford, J. D., Berrang-Ford, L., King, M., & Furgal, C. (2010). Vulnerability of Aboriginal health systems in Canada to climate change. *Global Environmental Change*, *20*(4), 668–680. <https://doi.org/10.1016/j.gloenvcha.2010.05.003>

Ford, J. D., Clark, D. G., & Naylor, A. W. (2019). Food insecurity in Nunavut: Are we going from bad to worse? *Canadian Medical Association Journal*, *191*(20), E550–E551. <https://doi.org/10.1503/cmaj.190497>

Ford, J. D., Falk, K., Tesar, C., & Jacobsen, R. B. (2018). Adaptation and resilience. In *Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait region* (pp. 307–328). Oslo, Norway: Arctic Monitoring and Assessment Programme (AMAP).

Ford, J. D., & King, D. (2015). A framework for examining adaptation readiness. *Mitigation and Adaptation Strategies for Global Change*, *20*, 505–526. 10.1007/s11027-013-9505-8

Ford, J. D., Lardeau, M.-P., Blackett, H., Chatwood, S., & Kurszewski, D. (2013). Community food program use in Inuvik, Northwest Territories. *BMC Public Health*, *13*(1), 970. <https://doi.org/10.1186/1471-2458-13-970>

Ford, J. D., Tilleard, S., Berrang-Ford, L., Araos, M., Biesbroek, R., Lesnikowski, A., … Bizikova, L. (2016). Opinion: Big data has big potential for applications to climate change adaptation. *Proceedings of the National Academy of Sciences*, *113*(39), 10729–10732. <https://doi.org/10.1073/pnas.1614023113>

Ford, J. D., Willox, A. C., Chatwood, S., Furgal, C., Harper, S., Mauro, I., & Pearce, T. (2014). Adapting to the effects of climate change on Inuit health. *American Journal of Public Health*, *104*(S3), e9–e17. <https://doi.org/10.2105/AJPH.2013.301724>

Friel, S. (2019). It's a consumptagenic world. In N. Krieger (Ed.), *Climate Change and People's Health* (pp. 57–112). New York, NY: Oxford University Press. <https://doi.org/doi:10.1093/oso/9780190492731.001.0001>

Friel, S., Bowen, K., Campbell-Lendrum, D., Frumkin, H., McMichael, A. J. J., & Rasanathan, K. (2011). Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annual Review of Public Health*, *32*, 133–147. <https://doi.org/10.1146/annurev-publhealth-071910-140612>

Friel, S., & Ford, L. (2015). Systems, food security and human health. *Food Security*, *7*(2), 437–451. <https://doi.org/10.1007/s12571-015-0433-1>

Gaden, A., Ferguson, S. H., Harwood, L., Melling, H., Alikamik, J., & Stern, G. A. (2012). Western Canadian Arctic ringed seal organic contaminant trends in relation to sea ice break-up. *Environmental Science & Technology*, *46*(8), 4427–4433. <https://doi.org/10.1021/es204127j>

Gagné, D., Blanchet, R., Lauziere, J., Vaissière, É., Vézina, C., Ayotte, P., … Turgeon O'Brien, H. (2012). Traditional food consumption is associated with higher nutrient intakes in Inuit children attending childcare centres in Nunavik. *International Journal of Circumpolar Health*, *71*(1), 18401. <https://doi.org/10.3402/ijch.v71i0.18401>

Gibson, K., Kneen, C., & Houghton, J. (2004). *Making the connection: food security and public health*. The Community Nutritionists Council of BC. Retrieved from <https://bcfoodsecuritygateway.ca/wp-content/uploads/sites/2/2015/11/Making_the_Connection.pdf>

Golden, C. D., Allison, E. H., Cheung, W. W. L., Dey, M. M., Halpern, B. S., McCauley, D. J., … Myers, S. S. (2016). Nutrition: fall in fish catch threatens human health. *Nature*, *534*(7607), 317–320. <https://doi.org/10.1038/534317a>

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2973–2989. <https://doi.org/10.1098/rstb.2010.0158>

Goulson, D., Derwent, L. C., Hanley, M. E., Dunn, D. W., & Abolins, S. R. (2005). Predicting calyptrate fly populations from the weather, and probable consequences of climate change. *Journal of Applied Ecology*, *42*(5), 795–804. <https://doi.org/10.1111/j.1365-2664.2005.01078.x>

Government of Canada. (2016). *Environmental Contaminants*. Retrieved from <https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants.html>

Government of Canada. (2017). *Canadian Arctic Contaminants Assessment Report: Human Health Assessment 2017* (M. S. Curren, Ed.). Ottawa, ON. Retrieved from <https://unh.app.box.com/file/412682049405>

Government of Canada. (2019). *Diseases and conditions*. Retrieved from <https://www.canada.ca/en/public-health/services/diseases.html>

Government of Canada. (2020). *Treaties and agreements*. Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1100100028574/1529354437231>

Government of Northwest Territories. (2018). *2030 NWT climate change strategic framework*. Retrieved from <https://www.enr.gov.nt.ca/en/services/climate-change/2030-nwt-climate-change-strategic-framework>

Government of Nunavut, Government of Northwest Territories, & Government of Yukon. (2011). *Pan-territorial adaptation strategy: Moving forward on climate change adaptation in Canada's north*. Retrieved from <https://www.northernadaptation.ca/sites/default/files/Pan-Territorial_Adaptation_Strategy.pdf>

Government of Yukon. (2014). *Climate Change & public health*. Whitehorse, YK.

Greenwood, M., de Leeuw, S., & Lindsay, N. (2018). Challenges in health equity for Indigenous peoples in Canada. *The Lancet*, *391*(10131), 1645–1648. <https://doi.org/10.1016/S0140-6736(18)30177-6>

Greer, A., Ng, V., & Fisman, D. (2008). Climate change and infectious diseases in North America: the road ahead. *Canadian Medical Association Journal*, *178*(6), 715. <https://doi.org/10.1503/CMAJ.081325>

Gregory, P., Ingram, J., & Brklacich, M. (2005). Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1463), 2139–2148. <https://doi.org/10.1098/rstb.2005.1745>

Grey Bruce Health Unit. (2017). *Climate change and public health in Grey Bruce Health Unit: current conditions and future projections*. Owen Sound, ON.

Grey, S., & Patel, R. (2015). Food sovereignty as decolonization: Some contributions from Indigenous movements to food system and development politics. *Agriculture & Human Values*, *32*(3), <https://doi.org/431–444. 10.1007/s10460-014-9548-9>

Grimes, D. J., Johnson, C. N., Dillon, K. S., Flowers, A. R., Noriea, N. F., 3rd, & Berutti, T. (2009). What genomic sequence information has revealed about Vibrio ecology in the ocean--a review. *Microbial ecology*, *58*(3), 447–460. <https://doi.org/10.1007/s00248-009-9578-9>

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change*, *15*(3), 199–213. <https://doi.org/https://doi.org/10.1016/j.gloenvcha.2005.01.002>

Guyadeen, D., Thistlethwaite, J., & Henstra, D. (2019). Evaluating the quality of municipal climate change plans in Canada. *Climatic Change*, *152*, 121–143. <https://doi.org/10.1007/s10584-018-2312-1>

Hald, B., Skovgård, H., Pedersen, K., & Bunkenborg, H. (2008). Influxed insects as vectors for *Campylobacter jejuni* and *Campylobacter coli* in Danish broiler houses. *Poultry Science*, *87*(7), 1428–1434. <https://doi.org/10.3382/ps.2007-00301>

Halifax Regional Municipality. (2010). *HRM climate SMART community action guide to climate change and emergency preparedness*.

Halseth, R. (2015). *The nutritional health of the First Nations and Métis of the Northwest Territories: A review of current knowledge and gaps*. Prince George, BC. Retrieved from <http://www.nccah-ccnsa.ca/Publications/Lists/Publications/Attachments/141/2015_04_21_RPT_DietNutritionNWT_EN_Web.pdf>

Hansen, L. J., & Hoffman, J. R. (2011). Assessing vulnerability to climate change. In *Climate Savvy* (pp. 55–69). Island Press. <https://doi.org/10.5822/978-1-59726-988-9_5>

Harper, S. L., Berrang-Ford, L., Carcamo, C., Cunsolo, A., Edge, V. L., Ford, J. D., … Namanya, D. B. (2019). The Indigenous Climate–Food–Health Nexus. In L. R. Mason, & J. Rigg (Eds.), *People and Climate Change: Vulnerability, Adaptation, and Social Justice* (pp. 184-207). Oxford University Press.

Harper, S. L., Edge, V. L., Ford, J., Cunsolo, A., Wood, M., Team, I. R., … Namanya, D. B. (2015a). Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health*, *15*(1), 605. <https://doi.org/10.1186/s12889-015-1874-3>

Harper, S. L., Edge, V. L., Ford, J., Thomas, M. K., Pearl, D. L., Shirley, J., … McEwen, S. A. (2015b). Acute gastrointestinal illness in two Inuit communities: burden of illness in Rigolet and Iqaluit, Canada. *Epidemiology and Infection*, *143*(14), 3048–3063. <https://doi.org/10.1017/S0950268814003744>

Harper, S. L., Edge, V. L., Ford, J., Thomas, M. K., Pearl, D. L., Shirley, J., … McEwen, S. A. (2015c). Healthcare use for acute gastrointestinal illness in two Inuit communities: Rigolet and Iqaluit, Canada. *International Journal of Circumpolar Health*, *74*, 26290. <https://doi.org/10.3402/ijch.v74.26290>

Harper, S. L., Edge, V. L., Schuster-Wallace, C. J., Ar-Rushdi, M., & McEwen, S. A. (2011). Improving Aboriginal health data capture: evidence from a health registry evaluation. *Epidemiology and Infection*, *139*(11), 1774—1783. <https://doi.org/10.1017/s095026881000275x>

Health Canada. (2019). *Climate Change and Health Adaptation Capacity Building Program (HealthADAPT)*. Retrieved from <https://www.canada.ca/en/health-canada/news/2019/04/backgrounder-climate-change-and-health-adaptation-capacity-building-program-healthadapt.html>

Health Canada. (2020). *Determining food security status*. Retrieved from <https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/household-food-insecurity-canada-overview/determining-food-security-status-food-nutrition-surveillance-health-canada.html>

Hedlund, C., Blomstedt, Y., & Schumann, B. (2014). Association of climatic factors with infectious diseases in the Arctic and subarctic region – a systematic review. *Global Health Action*, *7*(1), 24161. <https://doi.org/10.3402/gha.v7.24161>

Heiman, K. E., Mody, R. K., Johnson, S. D., Griffin, P. M., & Gould, L. H. (2015). *Escherichia coli* O157 outbreaks in the United States, 2003–2012. *Emerging Infectious Diseases*, *21*(8), 1293. <https://doi.org/10.3201/eid2108.141364>

Hellberg, R. S., & Chu, E. (2015). Effects of climate change on the persistence and dispersal of foodborne bacterial pathogens in the outdoor environment: A review. *Critical Reviews in Microbiology*, *42*(4), 548–572. <https://doi.org/10.3109/1040841X.2014.972335>

Henstra, D. (2017). Climate adaptation in Canada : Governing a complex policy regime. *Review of Policy Research*, *34*(3), 378–399. <https://doi.org/10.1111/ropr.12236>

Hess, J. J., McDowell, J. Z., & Luber, G. (2012). Integrating climate change adaptation into public health practice: using adaptive management to increase adaptive capacity and build resilience. *Environmental Health Perspectives*, *120*(2), 171–179. <https://doi.org/10.1289/ehp.1103515>

High Level Panel of Experts (HLPE). (2017). *Nutrition and food systems*. Rome, Italy. Retrieved from <http://www.fao.org/3/i7846e/i7846e.pdf>

Huang, C., Vaneckova, P., Wang, X., FitzGerald, G., Guo, Y., & Tong, S. (2011). Constraints and barriers to public health adaptation to climate change: a review of the literature. *American Journal of Preventive Medicine*, *40*(2), 183–190. <https://doi.org/10.1016/J.AMEPRE.2010.10.025>

Huet, C., Rosol, R., & Egeland, G. M. (2012). The prevalence of food insecurity is high and the diet quality poor in Inuit communities. *The Journal of Nutrition*, *142*(3), 541–547. <https://doi.org/10.3945/jn.111.149278>

Ingram, J. (2009). Food system concepts. In R. Rabbinge & A. Linneman (Eds.), *European food systems in a changing world* (pp. 9–15). ESF-COST.

Institute for Health Metrics and Evaluation (IHME). (2016). *Global burden of disease arrow diagram.*

Institut national de santé publique du Québec (INSPQ). (n.d.). *Mon Climat, Ma Santé*. Retrieved from <http://www.monclimatmasante.qc.ca/>

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change* (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, … T. Waterfield, Eds.). Retrieved from <https://www.ipcc.ch/sr15/>

Intergovernmental Panel on Climate Change (IPCC). (2019a). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (P. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. Roberts, … J. Malley, Eds.). Retrieved from <https://www.ipcc.ch/srccl/>

Intergovernmental Panel on Climate Change (IPCC). (2019b). *Special Report on the Ocean and Cryosphere in a Changing Climate* (H.-O. Pörtner, D. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, … N. Weyer, Eds.). Retrieved from <https://www.ipcc.ch/srocc/>

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2018). *The regional assessment report on biodiversity and ecosystem services for the Americas* (J. Rice, C. S. Seixas, M. E. Zaccagnini, M. Bedoya- Gaitán, N. Valderrama, C. B. Anderson, … J. S. Farinaci, Eds.). Germany: Bonn.

Inuit Tapiriit Kanatami (ITK). (2019). *National Inuit Climate Change Strategy*. Retrieved from <https://www.itk.ca/wp-content/uploads/2019/06/ITK_Climate-Change-Strategy_English.pdf>

Jaykus, L., Woolridge, M., Frank, J., Miraglia, M., McQuatters-Gollop, A., Tirado, C., … Friel, M. (2008). *Climate change: Implications for food safety*. Rome, Italy.

Jenkins, E. J., Castrodale, L. J., de Rosemond, S. J. C., Dixon, B. R., Elmore, S. A., Gesy, K. M., … Thompson, R. C. A. (2013). Tradition and transition: parasitic zoonoses of people and animals in Alaska, Northern Canada, and Greenland. *Advances in Parasitology*, *82*, 33–204. <https://doi.org/10.1016/B978-0-12-407706-5.00002-2>

Jessiman-Perreault, G., & McIntyre, L. (2017). The household food insecurity gradient and potential reductions in adverse population mental health outcomes in Canadian adults. *SSM - Population Health*, *3*, 464–472. <https://doi.org/10.1016/j.ssmph.2017.05.013>

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Doll, P., … Mwakalila, S. S. (2014). Freshwater Resources. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *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 on Climate Change* (pp. 229–269). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Johnson-Down, L., & Egeland, G. M. (2010). Adequate nutrient intakes are associated with traditional food consumption in Nunavut Inuit children aged 3–5 years. *The Journal of Nutrition*, *140*(7), 1311–1316. <https://doi.org/10.3945/jn.109.117887>

Julie, D., Solen, L., Antoine, V., Jaufrey, C., Annick, D., & Dominique, H.-H. (2010). Ecology of pathogenic and non-pathogenic *Vibrio parahaemolyticus* on the French Atlantic coast. Effects of temperature, salinity, turbidity and chlorophyll a. *Environmental Microbiology*, *12*(4), 929–937. <https://doi.org/10.1111/j.1462- 2920.2009.02136.x>

Jung, J. K. H., & Skinner, K. (2017). Enteric Disease Outbreaks: Foodborne and waterborne illness among Canadian Indigenous populations: A scoping review. *Canada Communicable Disease Report*, *43*(1), <https://doi.org/7.10.14745/ccdr.v43i01a02>

Kapilashrami, A., & Hankivsky, O. (2018). Intersectionality and why it matters to global health. *The Lancet*, *391*(10140), 2589–2591. <https://doi.org/10.1016/S0140-6736(18)31431-4>

Keen, J. E., Laegreid, W. W., Chitko Mckown, C. G., Bono, J. L., Fox, J. M., Clawson, M., & Heaton, M. (2003). Effect of exogenous glucocorticoids and dietary change on winter and summer STEC O157 fecal shedding in naturally-infected beef cattle. In *Research Workers in Animal Diseases Conference Proceedings*.

Kenny, T.-A., Fillion, M., Simpkin, S., Wesche, S. D., & Chan, H. M. (2018). Caribou (*Rangifer tarandus*) and Inuit nutrition security in Canada. *EcoHealth*, *15*(3), 590–607. <https://doi.org/10.1007/s10393-018-1348-z>

Kermoal, N., & Altamirano-Jiménez, I. (Eds.). (2016). *Living on the land: Indigenous women's understanding of place*. Athabasca University Press.

Khan, S., Barhoumi, R., Burghardt, R., Liu, S., Kim, K., & Safe, S. (2006). Molecular mechanism of inhibitory aryl hydrocarbon receptor-estrogen receptor/Sp1 cross talk in breast cancer cells. *Molecular Endocrinology*, *20*(9), 2199–2214. <https://doi.org/10.1210/me.2006-0100>

King, U., & Furgal, C. (2014). Is hunting still healthy? Understanding the interrelationships between indigenous participation in land-based practices and human-environmental health. *International Journal of Environmental Research and Public Health*, *11*(6), 5751–5782. <https://doi.org/10.3390/ijerph110605751>

Kipp, A., Cunsolo, A., Vodden, K., King, N., Manners, S., & Harper, S. L. (2019). Climate change impacts on health and wellbeing in rural and remote regions across Canada: A synthesis of the literature. *Health Promotion and Chronic Disease Prevention in Canada*, *39*(4). <https://doi.org/10.24095/hpcdp.39.4.02>

Konrad, S., Paduraru, P., Romero-Barrios, P., Henderson, S. B., & Galanis, E. (2017). Remote sensing measurements of sea surface temperature as an indicator of *Vibrio parahaemolyticus* in oyster meat and human illnesses. *Environmental Health*, *16*(1), 92. <https://doi.org/https://dx.doi.org/10.1186/s12940-017-0301-x>

Kovats, R. S., Edwards, S. J., Hajat, S., Armstrong, B. G., Ebi, K. L., & Menne, B. (2004). The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. *Epidemiology & Infection*, *132*(3), 443–453. <https://doi.org/10.1017/s0950268804001992>

Kuhnlein, H. V, & Chan, H. M. (2000). Environment and contaminants in traditional food systems of Northern Indigenous peoples. *Annual Review of Nutrition*, *20*(1), 595–626. <https://doi.org/10.1146/annurev.nutr.20.1.595>

Labbé, J., Ford, J. D., Araos, M., & Flynn, M. (2017). The government-led climate change adaptation landscape in Nunavut, Canada. *Environmental Reviews*, *25*(1), 12–25. <https://doi.org/10.1139/er-2016-0032>

Lafferty, K. D., Porter, J. W., & Ford, S. E. (2004). Are diseases increasing in the ocean? *Annual Review of Ecology, Evolution, and Systematics*, *35*, 31–54. <https://doi.org/10.1146/annurev.ecolsys.35.021103.105704>

Laidler, G. J., Ford, J. D., Gough, W. A., Ikummaq, T., Gagnon, A. S., Kowal, S., … Irngaut, C. (2009). Travelling and hunting in a changing Arctic: assessing Inuit vulnerability to sea ice change in Igloolik, Nunavut. *Climatic Change*, *94*, 363–397. <https://doi.org/10.1007/s10584-008-9512-z>

Lake, I. R. (2017). Food-borne disease and climate change in the United Kingdom. *Environmental Health*, *16*(S1), 117. <https://doi.org/10.1186/s12940-017-0327-0>

Lake, I. R., & Barker, G. C. (2018). Climate change, foodborne pathogens and illness in higher-income countries. *Current Environmental Health Reports*, *5*(1), 187–196. <https://doi.org/10.1007/s40572-018-0189-9>

Lake, I. R., Foxall, C. D., Fernandes, A., Lewis, M., Rose, M., White, O., … Mortimer, D. (2015). The effects of flooding on dioxin and PCB levels in food produced on industrial river catchments. *Environment International*, *77*, 106–115. <https://doi.org/10.1016/J.ENVINT.2015.01.006>

Lake, I. R., Foxall, C. D., Lovett, A. A., Fernandes, A., Dowding, A., White, S., & Rose, M. (2005). Effects of river flooding on PCDD/F and PCB levels in cows' milk, soil, and grass. *Environmental Science & Technology*, *39*(23), 9033–9038. <https://doi.org/10.1021/es051433a>

Lake, I. R., Gillespie, I. A., Bentham, G., Nichols, G. L., Lane, C., Adak, G. K., & Threlfall, E. J. (2009). A re-evaluation of the impact of temperature and climate change on foodborne illness. *Epidemiology & Infection*, *137*(11), 1538–1547. <https://doi.org/0.1017/S0950268809002477>

Lake, I. R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A. B. A., Draper, A., … Waldron, K. W. (2012). Climate change and food security: health impacts in developed countries. *Environmental Health Perspectives*, *120*(11), 1520–1526. <https://doi.org/10.1289/ehp.1104424>

Lal, A., Hales, S., French, N., & Baker, M. G. (2012). Seasonality in human zoonotic enteric diseases: a systematic review. *PLoS One*, *7*(4), e31883. <https://doi.org/10.1371/journal.pone.0031883>

Lam, S., Dodd, W., Skinner, K., Papadopoulos, A., Zivot, C., Ford, J., … Harper, S. L. (2019). Community-based monitoring of Indigenous food security in a changing climate: global trends and future directions. *Environmental Research Letters*, *14*(7), 073002. <https://doi.org/10.1088/1748-9326/ab13e4>

Landauer, M., & Juhola, S. (2019). Loss and damage in the rapidly changing Arctic. In R. Mechler, L. Bouwer, T. Schinko, S. Surminski, & J. Linnerooth-Bayer (Eds.), *Loss and Damage from Climate Change. Climate Risk Management, Policy and Governance* (pp. 425–447). Springer, Cham. <https://doi.org/10.1007/978-3-319-72026-5_18>

Larsen, J. N., Anisimov, O. A., Constable, A., Hollowed, A. B., Maynard, N., Prestrud, P., … Stone, J. M. R. (2014). Polar Regions. In V. R. Barros, C. B. Field, D. J. Dokken, M. B. Mastrandrea, K. J. Mach, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1567–1612). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Lemke, S., & Delormier, T. (2017). Indigenous Peoples' food systems, nutrition, and gender: Conceptual and methodological considerations. *Maternal & Child Nutrition*, *13*, e12499. <https://doi.org/10.1111/mcn.12499>

Lemmen, D. S., Warren, F. J., Lacroix, J., & Bush, E. (Eds.). (2008). *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ottawa, ON: Natural Resources Canada.

Lesnikowski, A., Belfer, E., Rodman, E., Smith, J., Biesbroek, R., Wilkerson, J., … Berrang-Ford, L. (2019). Frontiers in data analytics for adaptation research: Topic modeling. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(3), e576. <https://doi.org/10.1002/wcc.576>

Lesnikowski, A., Ford, J., Berrang-Ford, L., Paterson, J., Barrera, M., & Heymann, J. (2011). Adapting to health impacts of climate change: a study of UNFCCC Annex I parties. *Environmental Research Letters*, *6*(4), 044009. <https://doi.org/10.1088/1748-9326/6/4/044009>

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., & Heymann, J. (2016). National-level progress on adaptation. *Nature Climate Change*, *6*(3), 261–264. <https://doi.org/10.1038/nclimate2863>

Levison, M. M., Butler, A. J., Rebellato, S., Armstrong, B., Whelan, M., & Gardner, C. (2018). Development of a climate change vulnerability assessment using a public health lens to determine local health vulnerabilities: an Ontario health unit experience. *International Journal of Environmental Research and Public Health*, *15*(10), 2237. <https://doi.org/10.3390/ijerph15102237>

Levison, M. M., Whelan, M., & Butler, A. (2017). *A changing climate: assessing health impacts and vulnerabilities due to climate change within Simcoe Muskoka*. Simcoe Muskoka District Health Unit.

Li, N., Dachner, N., Tarasuk, V., Zhang, R., Kurrein, M., Harris, T., Gustin, S., & Rasal, D. (2016). *Priority Health Equity Indicators for British Columbia: Household Food Insecurity Indicator Report.* Vancouver, BC: Provincial Health Services Authority and PROOF.

Liu, C., Hofstra, N., & Franz, E. (2013). Impacts of climate change on the microbial safety of pre-harvest leafy green vegetables as indicated by *Escherichia coli* O157 and Salmonella spp. *International Journal of Food Microbiology*, *163*(2–3), 119–128. <https://doi.org/10.1016/j.ijfoodmicro.2013.02.026>

Lock, K., Stuckler, D., Charlesworth, K., & McKee, M. (2009). Potential causes and health effects of rising global food prices. *BMJ (Clinical research ed.)*, *339*, b2403. <https://doi.org/10.1136/bmj.b2403>

Lopez, R., & Goldoftas, B. (2009). The urban elderly in the United States: health status and the environment. *Reviews on Environmental Health*, *24*(1), 47–57. <https://doi.org/10.1515/REVEH.2009.24.1.47>

Ma, J., Hung, H., Tian, C., & Kallenborn, R. (2011). Revolatilization of persistent organic pollutants in the Arctic induced by climate change. *Nature Climate Change*, *1*(5), 255–260. <https://doi.org/10.1038/nclimate1167>

Macdiarmid, J. I., & Whybrow, S. (2019). Nutrition from a climate change perspective. In A. Gallagher (Ed.), *Proceedings of the Nutrition Society* (pp. 1–8). Cambridge University Press. <https://doi.org/10.1017/S0029665118002896>

MacFadden, D. R., McGough, S. F., Fisman, D., Santillana, M., & Brownstein, J. S. (2018). Antibiotic resistance increases with local temperature. *Nature Climate Change*, *8*(6), 510–514. <https://doi.org/10.1038/s41558-018-0161-6>

Magnan, A. K., Schipper, E. L. F., Burkett, M., Bharwani, S., Burton, I., & Eriksen, S. H. (2016). Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *7*, 646–665. <https://doi.org/10.1002/wcc.409>

Manciocco, A., Calamandrei, G., & Alleva, E. (2014). Global warming and environmental contaminants in aquatic organisms: the need of the etho-toxicology approach. *Chemosphere*, *100*, 1–7. <https://doi.org/10.1016/j.chemosphere.2013.12.072>

Martens, T., Cidro, J., Hart, M. A., & McLachlan, S. (2016). Understanding Indigenous food sovereignty through an Indigenous research paradigm. *Journal of Indigenous Social Development*, *5*(1), 18-37.

Martinez-Urtaza, J., Bowers, J. C., Trinanes, J., & DePaola, A. (2010). Climate anomalies and the increasing risk of *Vibrio parahaemolyticus* and *Vibrio vulnificus* illnesses. *Food Research International*, *43*(7), 1780–1790. <https://doi.org/10.1016/j.foodres.2010.04.001>

Marushka, L., Batal, M., Sharp, D., Schwartz, H., Ing, A., Fediuk, K., … Chan, H. M. (2017). Fish consumption is inversely associated with type 2 diabetes in Manitoba First Nations communities. *FACETS*, *2*, 795–818. <https://doi.org/10.1139/facets-2017-0023>

Marushka, L., Kenny, T.-A. A., Batal, M., Cheung, W. W. L., Fediuk, K., Golden, C. D., … Chan, H. M. (2019). Potential impacts of climate-related decline of seafood harvest on nutritional status of coastal First Nations in British Columbia, Canada. *PLoS ONE*, *14*(2). <https://doi.org/10.1371/journal.pone.0211473>

Marvin, H. J. P., Kleter, G. A., Noordam, M. Y., Franz, E., Willems, D. J. M., & Boxall, A. (2013). Proactive systems for early warning of potential impacts of natural disasters on food safety: climate-change-induced extreme events as case in point. *Food Control*, *34*(2), 444–456. https://doi.org/https://doi.org/10.1016/j.foodcont.2013.04.037

Mbow, C., Rosenzweig, C., Barioni, L., Benton, T., Herrero, M., Krishnapillai, M., … Xu, Y. (2019). Food security. In P. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, … J. Malley (Eds.), *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Retrieved from <https://www.ipcc.ch/srccl/>

McLeod, L., & Veall, M. (2006). The dynamics of food insecurity and overall health: evidence from the Canadian National Population Health Survey. *Applied Economics*, *38*(18), 2131–2146. <https://doi.org/10.1080/00036840500427429>

Medical Officer of Health. (2013). *Exploring Health and Social Impacts of Climate Change in Toronto*. Toronto, ON.

Metro Vancouver. (2016). *Regional food system action plan*. Vancouver, BC.

Milazzo, A., Giles, L. C., Zhang, Y., Koehler, A. P., Hiller, J. E., & Bi, P. (2017). Factors Influencing Knowledge, Food Safety Practices and Food Preferences During Warm Weather of Salmonella and Campylobacter Cases in South Australia. *Foodborne Pathogens and Disease*, *14*(3), 125–131. <https://doi.org/10.1089/fpd.2016.2201>

Miraglia, M., Marvin, H. J. P., Kleter, G. A., Battilani, P., Brera, C., Coni, E., … Vespermann, A. (2009). Climate change and food safety: an emerging issue with special focus on Europe. *Food and Chemical Toxicology*, *47*(5), 1009–1021. <https://doi.org/10.1016/j.fct.2009.02.005>

Morrison, D. (2011). Indigenous food sovereignty: a model for social learning. In A. A. Desmarais, N. Wiebe, & H. Wittman (Eds.), *Food Sovereignty in Canada: Creating Just and Sustainable Food Systems* (pp. 97–113). Fernwood Publishing.

Moser, S. C. (2014). Communicating adaptation to climate change: the art and science of public engagement when climate change comes home. *Climate Change*, *5*(3), 337–358. <https://doi.org/10.1002/wcc.276>

Moulton, A. D., & Schramm, P. J. (2017). Climate change and public health surveillance. *Journal of Public Health Management and Practice*, *23*(6), 618–626. <https://doi.org/10.1097/PHH.0000000000000550>

Muldoon, K. A., Duff, P. K., Fielden, S., & Anema, A. (2013). Food insufficiency is associated with psychiatric morbidity in a nationally representative study of mental illness among food insecure Canadians. *Social Psychiatry and Psychiatric Epidemiology*, *48*(5), 795–803. <https://doi.org/10.1007/s00127-012-0597-3>

Muncke, J., Myers, J. P., Scheringer, M., & Porta, M. (2014). Food packaging and migration of food contact materials: will epidemiologists rise to the neotoxic challenge? *Journal of Epidemiology and Community Health*, *68*(7), 592–594. <https://doi.org/10.1136/jech-2013-202593>

Municipal Affairs and Environment. (2019). *The way forward on climate change in Newfoundland and Labrador*. St. John's, NL.

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., … Huybers, P. (2017). Climate change and global food systems: potential impacts on food security and undernutrition. *Annual Review of Public Health*, *38*, 259–277. <https://doi.org/10.1146/annurev-publhealth-031816-044356>

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A. J., … Usui, Y. (2014). Increasing CO_2 threatens human nutrition. *Nature*, *510*, 139–142. <https://doi.org/10.1038/nature13179>

Nelson, M. C., Ingram, S. E., Dugmore, A. J., Streeter, R., Peeples, M. A., Mcgovern, T. H., … Smiarowski, K. (2016). Climate challenges, vulnerabilities, and food security. *PNAS*, *113*(2), 298–303. <https://doi.org/10.1073/pnas.1506494113>

Neufeld, H. T. (2020). Socio-Historical Influences and Impacts on Indigenous Food Systems in Southwestern Ontario: The Experiences of Elder Women Living On-and Off-Reserve. In P. Settee, & S. Shukla (Eds.), *Indigenous Food Systems: Concepts, Cases, and Conversations* (pp. 251). Canadian Scholars' Press.

Ngoen-Klan, R., Moophayak, K., Klong-Klaew, T., Irvine, K. N., Sukontason, K. L., Prangkio, C., … Sukontason, K. (2011). Do climatic and physical factors affect populations of the blow fly *Chrysomya megacephala* and house fly *Musca domestica*? *Parasitology Research*, *109*(5), 1279–1292. <https://doi.org/10.1007/s00436-011-2372-x>

Northern Contaminants Program (NCP). (2013). *Canadian Arctic Contaminants Assessment Report III on Persistent Organic Pollutants* (D. Muir, P. Kurt-Karakus, J. Stow, Eds.). Ottawa, ON: Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada.

Nourish. (n.d.). *The Nourish Innovator Program*. Retrieved from <https://www.nourishhealthcare.ca/about-nourish>

Nova Scotia Environment. (2014). *Agriculture.*

Nunavut Food Security Coalition (NFSC). (2014). *Nunavut Food Security Strategy and Action Plan 2014-16*. Retrieved from <https://www.nunavutfoodsecurity.ca/sites/default/files/files/Resources/Strategy/NunavutFoodSecurityStrategy_ENGLISH.pdf>

Olazabal, M., Galarraga, I., Ford, J., Murieta, E. S. De, & Lesnikowski, A. (2019). Are local climate adaptation policies credible? A conceptual and operational assessment framework. *International Journal of Urban Sustainable Development*, *11*(3), 1–15. <https://doi.org/10.1080/19463138.2019.1583234>

Organ, J., Castleden, H., Furgal, C., Sheldon, T., & Hart, C. (2014). Contemporary programs in support of traditional ways: Inuit perspectives on community freezers as a mechanism to alleviate pressures of wild food access in Nain, Nunatsiavut. *Health and Place*, *30*, 251–259. <https://doi.org/10.1016/j.healthplace.2014.09.012>

O'Riordan, T., & Lenton, T. (2013). *Addressing tipping points for a precarious future*. Oxford, United Kingdom: Oxford University Press. <https://doi.org/10.5871/bacad/9780197265536.001.0001>

Palko, K., & Lemmen, D. S. (Eds.). (2017). *Climate risks and adaptation practices for the Canadian transportation sector 2016*. Ottawa, ON: Government of Canada.

Pangloli, P., Dje, Y., Ahmed, O., Doane, C. A., Oliver, S. P., & Draughon, F. A. (2008). Seasonal incidence and molecular characterization of Salmonella from dairy cows, calves, and farm environment. *Foodborne Pathogens and Disease*, *5*(1), 87–96. <https://doi.org/10.1089/fpd.2008.0048>

Pardhan-Ali, A., Berke, O., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., … McEwen, S. A. (2012a). A spatial and temporal analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *International Journal of Health Geographics*, *11*(1), 17. <https://doi.org/10.1186/1476-072X-11-17>

Pardhan-Ali, A., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., Santos, M., & McEwen, S. A. (2012b). A descriptive analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *BMJ Open*, *2*(4), e000732. <https://doi.org/10.1136/bmjopen-2011-000732>

Pardhan-Ali, A., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., Santos, M., & McEwen, S. A. (2013). Community-level risk factors for notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *BMC Public Health*, *13*(1), 63. <https://doi.org/10.1186/1471-2458-13-63>

Pardue, J., Moe, W., McInnis, D., Thibodeaux, L., Valsaraj, K., Maciasz, E., … Yuan, Q. (2005). Chemical and microbiological parameters in New Orleans floodwater following Hurricane Katrina. *Environmental Science & Technology*, *39*(22), 8591–8599. <https://doi.org/10.1021/es0518631>

Park, M. S., Park, K. H., & Bahk, G. J. (2018). Interrelationships between multiple climatic factors and incidence of foodborne diseases. *International Journal of Environmental Research and Public Health*, *15*(11), 2482. <https://doi.org/10.3390/ijerph15112482>

Parlee, B., & Berkes, F. (2005). Health of the land, health of the people: a case study on Gwich'in berry harvesting in northern Canada. *EcoHealth*, *2*(2), 127–137. <https://doi.org/10.1007/s10393-005-3870-z>

Parveen, S., Hettiarachchi, K. A., Bowers, J., Jones, J. L., Tamplin, M. L., McKay, R.,... DePaola, A. (2008). Seasonal distribution of total and pathogenic *Vibrio parahaemolyticus* in Chesapeake Bay oysters and waters. *International Journal of Food Microbiology*, *128*, 354–361. <https://doi.org/10.1016/j.ijfoodmicro.2008.09.019>

Paterson, J. A., Ford, J., Berrang-Ford, L., Lesnikowski, A., Berry, P., Henderson, J., & Heymann, J. (2012). Adaptation to climate change in the Ontario public health sector. *BMC Public Health*, *12*(1). <https://doi.org/10.1186/1471-2458-12-452>

Patriarca, A., & Fernández Pinto, V. (2017). Prevalence of mycotoxins in foods and decontamination. *Current Opinion in Food Science*, *14*, 50–60. <https://doi.org/10.1016/J.COFS.2017.01.011>

Pinstrup-Andersen, P. (2013). Contemporary food policy challenges and opportunities. *Australian Journal of Agricultural and Resource Economics*, *58*(4), 504–518. <https://doi.org/10.1111/1467-8489.12019>

Planning and Development Department. (2013). *Agriculture protection and enhancement strategy in Surrey*. Surrey, BC.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, M. S., Iqbal, M. M., … Travasso, M. I. (2014). Food security and food production systems. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *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 on Climate Change* (pp. 485–533). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Pouillot, R., Hoelzer, K., Chen, Y., & Dennis, S. B. (2015). Listeria monocytogenes dose response revisited- incorporating adjustments for variability in strain virulence and host susceptibility. *Risk Analysis*, *35*(1), 90–108. <https://doi.org/10.1111/risa.12235>

PROOF. (2018). *Latest household food insecurity data now available*. Retrieved from <https://proof.utoronto.ca/new-data-available/>

Public Health Agency of Canada (PHAC). (2017). *FoodNet Canada Annual Report 2017*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/services/surveillance/foodnet-canada/publications/foodnet-canada-annual-report-2017.html>

Public Health Agency of Canada (PHAC). (2018). *Inequalities in food insecurity in Canada*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/services/publications/science-research-data/inequalities-food-insecurity-canada-infographic.html>

Rahel, F. J., & Olden, J. D. (2008). Assessing the effects of climate change on aquatic invasive species. *Conservation Biology*, *22*(3), 521–533. <https://doi.org/10.1111/j.1523-1739.2008.00950.x>

Rangel, J. M., Sparling, P. H., Crowe, C., Griffin, P. M., & Swerdlow, D. L. (2005). Epidemiology of *Escherichia coli* O157:H7 outbreaks, United States, 1982–2002. *Emerging Infectious Diseases*, *11*(4), 603. <https://doi.org/10.3201/eid1104.040739>

Rapinski, M., Cuerrier, A., Harris, C., Elders of Ivujivik, Elders of Kangiqsujuaq, & Lemire, M. (2018). Inuit perception of marine organisms: From folk classification to food harvest. *Journal of Ethnobiology*, *38*(3), 333–355. <https://doi.org/10.2993/0278-0771-38.3.333>

Ratelle, M., Skinner, K., Laird, M. J., Majowicz, S., Brandow, D., Packull-McCormick, S., … Laird, B. D. (2018). Implementation of human biomonitoring in the Dehcho region of the Northwest Territories, Canada (2016–2017). *Archives of Public Health*, *76*(1), 73. <https://doi.org/10.1186/s13690-018-0318-9>

Ravel, A., Smolina, E., Sargeant, J. M., Cook, A., Marshall, B., Fleury, M. D., & Pollari, F. (2010). Seasonality in human salmonellosis: assessment of human activities and chicken contamination as driving factors. *Foodborne Pathogens and Disease*, *7*(7), 785–794. <https://doi.org/10.1089/fpd.2009.0460>

Ready, E. (2016). Challenges in the Assessment of Inuit Food Security. *ARCTIC*, *69*(3), 266–280. <https://doi.org/10.14430/arctic4579>

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

Rigét, F., Vorkamp, K., Bossi, R., Sonne, C., Letcher, R. J., & Dietz, R. (2016). Twenty years of monitoring of persistent organic pollutants in Greenland biota. A review. *Environmental Pollution (Barking, Essex: 1987)*, *217*, 114–123. <https://doi.org/10.1016/j.envpol.2015.11.006>

Roberts, M., & Cooke, R. (2020). Low on food, blizzard-weary St. John's shoppers head straight to supermarkets. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/newfoundland-labrador/grocery-stores-open-st-john-s-1.5433593>

Romero-Lankao, P., Smith, J., Davidson, D., Diffenbaugh, N., Kinney, P., Kirshen, P., … Villers Ruiz, L. (2014). North America. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1439–1498). Cambridge, UK and New York, USA: Cambridge University Press.

Rose, J., Epstein, P., Lipp, E., Sherman, B., Bernard, S., & Patz, J. (2001). Climate variability and change in the United States: potential impacts on water and foodborne diseases caused by microbiologic agents. *Environmental Health Perspectives*, *109*(S2), 211–221. <https://doi.org/10.1289/ehp.01109s2211>

Rose, N., Lunazzi, A., Dorenlor, V., Merbah, T., Eono, F., Eloit, M., … Pavio, N. (2011). High prevalence of Hepatitis E virus in French domestic pigs. *Comparative Immunology, Microbiology and Infectious Diseases*, *34*(5), 419–427. <https://doi.org/10.1016/j.cimid.2011.07.003>

Roser-Renouf, C., Maibach, E. W., & Li, J. (2016). Adapting to the changing climate: An assessment of local health department preparations for climate change-related health threats, 2008-2012. *PLoS ONE*, *11*(3). <https://doi.org/10.1371/journal.pone.0151558>

Rosol, R., Huet, C., Wood, M., Lennie, C., Osborne, G., & Egeland, G. M. (2011). Prevalence of affirmative responses to questions of food insecurity: International Polar Year Inuit Health Survey, 2007-2008. *International Journal of Circumpolar Health*, *70*(5), 488–497. <https://doi.org/10.3402/ijch.v70i5.17862>

Rosol, R., Powell-Hellyer, S., & Chan, H. M. (2016). Impacts of decline harvest of country food on nutrient intake among Inuit in Arctic Canada: impact of climate change and possible adaptation plan. *International Journal of Circumpolar Health*, *75*(1), 31127. <https://doi.org/10.3402/ijch.v75.31127>

Rudolph, K. R., & McLachlan, S. M. (2013). Seeking Indigenous food sovereignty: origins of and responses to the food crisis in northern Manitoba, Canada. *Local Environment*, *18*(9), 1079–1098. <https://doi.org/10.1080/13549839.2012.754741>

Sauchyn, D., Davidson, D., & Johnston, M. (2020). Prairie Provinces. In F.J. Warren, N. Lulham, & D.S. Lemmen (Eds.), *Canada in a Changing Climate: Regional Perspectives Report*. Ottawa, ON: Natural Resources Canada.

Sauchyn, D., Kulshreshtha, S., Barrow, E., Lemmen, D. S., Warren, F. J., Lacroix, J., & Bush, E. (2008). Prairies. In D. S. Lemmen, F. J. Warren, J. Lacroix, & E. Bush (Eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007* (pp. 275–328). Ottawa, ON: Natural Resources Canada.

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Middleton, J., & Harper, S. L. (2018). Responding to climate and environmental change impacts on human health via integrated surveillance in the Circumpolar North: A systematic realist review. *International Journal of Environmental Research and Public Health*, *15*(12), 2706. <https://doi.org/10.3390/ijerph15122706>

Schecter, A., & Gasiewicz, T. A. (Eds.). (2003). *Dioxins and health*. New York, NY: John Wiley & Sons, Inc. <https://doi.org/10.1002/0471722014>

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(50), 19703–19708. <https://doi.org/10.1073/pnas.0701976104>

Schnitter, R., & Berry, P. (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), 1–2531. <https://doi.org/10.3390/ijerph16142531>

Séguin, J. (Ed.). (2008). *Human Health in a changing climate: A Canadian assessment of vulnerabilities and adaptive capacity*. Ottawa, ON: Health Canada.

Semenza, J. C., Herbst, S., Rechenburg, A., Suk, J. E., Höser, C., Schreiber, C., & Kistemann, T. (2012a). Climate change impact assessment of food-and waterborne diseases. *Critical Reviews in Environmental Science and Technology*, *42*(8), 857–890. <https://doi.org/10.1080/10643389.2010.534706>

Semenza, J. C., Hoeser, C., Herbst, S., Rechenburg, A., Suk, J. E., Frechen, T., & Kistemann, T. (2012b). Knowledge mapping for climate change and food-and waterborne diseases. *Critical Reviews in Environmental Science and Technology*, *42*(4), 378–411. <https://doi.org/10.1080/10643389.2010.518520>

Semenza, J. C., Suk, J. E., Estevez, V., Ebi, K. L., & Lindgren, E. (2012c). Mapping climate change vulnerabilities to infectious diseases in Europe. *Environmental Health Perspectives*, *120*(3), 385–392. <https://doi.org/10.1289/ehp.1103805>

Skinner, K., Hanning, R. M., Desjardins, E., & Tsuji, L. J. (2013). Giving voice to food insecurity in a remote indigenous community in subarctic Ontario, Canada: traditional ways, ways to cope, ways forward. *BMC Public Health*, *13*, 427. <https://doi.org/10.1186/1471-2458-13-427>

Smith, B. A., & Fazil, A. (2019). How will climate change impact microbial foodborne disease in Canada? *Canada Communicable Disease Report*, *45*(4), 108–113. <https://doi.org/10.14745/ccdr.v45i04a05>

Smith, B. A., Meadows, S., Meyers, R., Parmley, E. J., & Fazil, A. (2019). Seasonality and zoonotic foodborne pathogens in Canada: relationships between climate and *Campylobacter*, *E. coli* and *Salmonella* in meat products. *Epidemiology and Infection*, *147*, e190. <https://doi.org/10.1017/S0950268819000797>

Smith, B. A., Ruthman, T., Sparling, E., Auld, H., Comer, N., Young, I., … Fazil, A. (2015). A risk modeling framework to evaluate the impacts of climate change and adaptation on food and water safety. *Food Research International*, *68*, 78–85. <https://doi.org/10.1016/J.FOODRES.2014.07.006>

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., … Sauerborn, R. (2014). Human health: impacts, adaptation, and co-benefits. In C. B. Field, V. Barros, D. Dokken, K. Mach, M. Mastrandrea, T. Bilir, … and L. L. W. B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea (Eds.), *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 on Climate Change* (pp. 709–754). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Sonnino, R. (2016). The new geography of food security: Exploring the potential of urban food strategies. *Geographical Journal*, *182*(2), 190–200. <https://doi.org/10.1111/geoj.12129>

Springmann, M., Mason-D'croz, D., Robinson, S., Garnett, T., Godfray, C. J., Gollin, D., … Scarborough, P. (2016). Global and regional health effects of future food production under climate change: a modelling study. *The Lancet*, *387*(10031), 1937–1946. <https://doi.org/10.1016/S0140-6736(15)01156-3>

Statistics Canada. (2009). Food in Canada. In *Human Activity and the Environment: Annual Statistics* (p. 166). Retrieved from <https://www150.statcan.gc.ca/n1/pub/16-201-x/2009000/part-partie1-eng.htm>

Statistics Canada. (2012). *Household food insecurity, 2011-2012. Data from the 2011-2012 Canadian Community Health Survey*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/82-625-x/2013001/article/11889-eng.htm>

Statistics Canada. (2015). *Food Security in Canada*. Ottawa, ON.

Statistics Canada. (2018). *Canadian Community Health Survey 2017-18*. Ottawa, ON.

Statistics Canada. (2020). *Table 17-10-0057-01 Projected population, by projection scenario, age and sex, as of July 1 (x 1,000)*. <https://doi.org/10.25318/1710005701-eng>

Steiner, L., & Neathway, C. (2019). *Indigenous food safety and security: Community adaptations in the wake of climate pressures*. Vancouver, BC.

Sugimura, T., Wakabayashi, K., Nakagama, H., & Nagao, M. (2004). Heterocyclic amines: Mutagens/carcinogens produced during cooking of meat and fish. *Cancer Science*, *95*(4), 290–299. <https://doi.org/10.1111/j.1349-7006.2004.tb03205.x>

Tarasuk, V., Cheng, J., de Oliveira, C., Dachner, N., Gundersen, C., & Kurdyak, P. (2015). Association between household food insecurity and annual health care costs. *CMAJ*, *187*(14), E-429-E436. <https://doi.org/10.1503/cmaj.150234/-/DC1>

Tarasuk, V., & Mitchell, A. (2020). *Household Food Insecurity in Canada, 2017-18*. Toronto, ON. <https://doi.org/10.1097/00008486-200510000-00003>

Tarasuk, V., Mitchell, A., & Dachner, N. (2016). *Household Food Insecurity in Canada, 2014. Research to Identify Policy Options to Reduce Food Insecurity (PROOF)*. Toronto, ON. Retrieved from <https://proof.utoronto.ca/resources/proof-annual-reports/annual-report-2014/>

The Royal Society. (2009). *Reaping the benefits: Science and the sustainable intensification of global agriculture*. Retrieved from <https://royalsociety.org/topics-policy/publications/2009/reaping-benefits/>

Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Fazil, A., Nesbitt, A., … Pollari, F. (2015). Estimates of foodborne illness-related hospitalizations and deaths in Canada for 30 specified pathogens and unspecified agents. *Foodborne Pathogens and Disease*, *12*(10), 820–827. <https://doi.org/10.1089/fpd.2015.1966>

Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Pollari, F., Fazil, A., … Marshall, B. (2013). Estimates of the burden of foodborne illness in Canada for 30 specified pathogens and unspecified agents, circa 2006. *Foodborne Pathogens and Disease*, *10*(7), 639–648.

Thomson, B., & Rose, M. (2011). Environmental contaminants in foods and feeds in the light of climate change. *Quality Assurance and Safety of Crops & Foods*, *3*(1), 2–11. <https://doi.org/10.1111/j.1757-837X.2010.00086.x>

Tirado, M. C., Clarke, R., Jaykus, L. A., McQuatters-Gollop, A., & Frank, J. M. (2010). Climate change and food safety: A review. *Food Research International*, *43*(7), 1745–1765. <https://doi.org/10.1016/J.FOODRES.2010.07.003>

Toronto Public Health (TPH). (2015). *A climate of concern: climate change and health strategy for Toronto 2015*. Toronto, ON.

Umlauf, G., Bidoglioa, G., Christopha, E., Kampheusb, J., Krügerc, F., Landmannd, D., … Stehr, D. (2005). The situation of PCDD/Fs and Dioxin-like PCBs after the flooding of River Elbe and Mulde in 2002. *Acta Hydrochimica et Hydrobiologica*, *33*(5), 543–554. <https://doi.org/10.1002/aheh.200400597>

Umlauf, G., Christoph, E., Lanzini, L., Savolainen, R., Skejo, H., Bidoglio, G., … Scherer, H. (2011). PCDD/F and dioxin-like PCB profiles in soils amended with sewage sludge, compost, farmyard manure, and mineral fertilizer since 1962. *Environmental Science and Pollution Research International*, *18*(3), 461–470. <https://doi.org/10.1007/s11356-010-0389-9>

Undeman, E., Brown, T. N., Wania, F., & McLachlan, M. S. (2010). Susceptibility of human populations to environmental exposure to organic contaminants. *Environmental Science & Technology*, *44*(16), 6249–6255. <https://doi.org/10.1021/es1009339>

US Environmental Protection Agency (USEPA). (2021). *Health Effects of Exposures to Mercury*. Retrieved from <https://www.epa.gov/mercury/health-effects-exposures-mercury>

U.S. Global Change Research Program (USGCRP). (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (A. Crimmins, J. Balbus, J. Gamble, C. Beard, J. Bell, D. Dodgen, … L. Ziska, Eds.). Washington, DC. Retrieved from <https://health2016.globalchange.gov/low/ClimateHealth2016_FullReport_small.pdf >

Valcour, J. E., Charron, D. F., Berke, O., Wilson, J. B., Edge, T., & Waltner-Toews, D. (2016). A descriptive analysis of the spatio-temporal distribution of enteric diseases in New Brunswick, Canada. *BMC Public Health*, *16*, 204. <https://doi.org/10.1186/s12889-016-2779-5>

Venegas-Vargas, C., Henderson, S., Khare, A., Mosci, R. E., Lehnert, J. D., Singh, P., … Rust, S. (2016). Factors associated with Shiga toxin-producing *Escherichia coli* shedding by dairy and beef cattle. *Applied and Environmental Microbiology*, *82*(16), 5049–5056. <https://doi.org/10.1128/AEM.00829-16>

Verner, G., Schütte, S., Knop, J., Sankoh, O., & Sauerborn, R. (2016). Health in climate change research from 1990 to 2014: positive trend, but still underperforming. *Global Health Action*, *9*(1), 1–9. <https://doi.org/10.3402/gha.v9.30723>

Ville de Montréal. (2018). *Montréal's resilient city strategy*. Montréal, QC. Retrieved from <https://resilient.montreal.ca/assets/doc/strategie-montreal-ville-resiliente-en.pdf>

Wang, H., & Horton, R. (2015). Tackling climate change: The greatest opportunity for global health. *The Lancet*, *386*(10006), 1798–1799. <https://doi.org/10.1016/S0140-6736(15)60931-X>

Warren, F. J., & Lemmen, D. S. (Eds.). (2014). *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Natural Resources Canada.

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., … Executive. (2015). Health and climate change: policy responses to protect public health. *The Lancet*, *386*(386), 1861–1914. <https://doi.org/10.1016/S0140-6736(15)60854-6>

Watts, N., Adger, W. N., Ayeb-Karlsson, S., Bai, Y., Byass, P., Campbell-Lendrum, D., … Costello, A. (2017). The Lancet Countdown: tracking progress on health and climate change. *The Lancet*, *389*(10074), 1151–1164. <https://doi.org/10.1016/S0140-6736(16)32124-9>

Weihe, P., Debes, F., Halling, J., Petersen, M. S., Muckle, G., Odland, J. Ø., Dudarev, A., Ayotte, P., Dewailly, É., Grandjean, P., & Bonefeld-Jørgensen, E. (2016). Health effects associated with measured levels of contaminants in the Arctic. *International Journal of Circumpolar Health*, *75*, 33805. <https://doi.org/10.3402/ijch.v75.33805>

Wesche, S. D., & Chan, H. M. (2010). Adapting to the impacts of climate change on food security among Inuit in the Western Canadian Arctic. *EcoHealth*, *7*(3), 361–373. <https://doi.org/10.1007/s10393-010-0344-8>

Wesche, S. D., O'Hare-Gordon, M. A. F., Robidoux, M. A., & Mason, C. W. (2016). Land-based programs in the Northwest Territories: Building Indigenous food security and well-being from the ground up. *Canadian Food Studies/La Revue Canadienne Des Études Sur l'alimentation*, *3*(2), 23–48. <https://doi.org/10.15353/cfs-rcea.v3i2.161>

Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508–513. <https://doi.org/10.1126/science.1239402>

Whyte, K. (2016). Indigenous food sovereignty, renewal and US settler colonialism. In M. Rawlinson, & C. Ward (Eds.), *The Routledge Handbook of Food Ethics*. Routledge.

Wong, J., & Schuchard, R. (2011). *Adapting to climate change: a guide for food, beverage, and agriculture companies*. San Francisco, California. Retrieved from <https://www.bsr.org/reports/BSR_Climate_Adaptation_Issue_Brief_Food_Bev_Ag2.pdf>

World Health Organization (WHO). (2008). *The world health report 2008: Primary health care (now more than ever)*. Geneva, Switzerland. Retrieved from <https://www.who.int/whr/2008/en/>

World Health Organization (WHO). (2014). *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s*. Geneva, Switzerland. Retrieved from <https://www.who.int/globalchange/publications/quantitative-risk-assessment/en/>

World Health Organization (WHO). (2017). *WHO guidelines on use of medically important antimicrobials in food-producing animals*. Retrieved from <https://www.who.int/foodsafety/areas_work/antimicrobial-resistance/cia_guidelines/en/>

Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment International*, *86*, 14–23. <https://doi.org/10.1016/j.envint.2015.09.007>

Yan, C., Liang, L. J., Zheng, K. Y., & Zhu, X. Q. (2016). Impact of environmental factors on the emergence, transmission and distribution of Toxoplasma gondii. *Parasites & vectors*, *9*, 137. <https://doi.org/10.1186/s13071-016-1432-6>

Young, I., Gropp, K., Fazil, A., & Smith, B. A. (2015). Knowledge synthesis to support risk assessment of climate change impacts on food and water safety: A case study of the effects of water temperature and salinity on *Vibrio parahaemolyticus* in raw oysters and harvest waters. *Food Research International*, *68*, 86–93. <https://doi.org/10.1016/j.foodres.2014.06.035>

Yusa, A., Berry, P., Cheng, J. J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health*, *12*(7), 8359–8412. <https://doi.org/10.3390/ijerph120708359>

Zelinkova, Z., & Wenzl, T. (2015). The occurrence of 16 EPA PAHs in food - a review. *Polycyclic Aromatic Compounds*, *35*(2–4), 248–284. <https://doi.org/10.1080/10406638.2014.918550>

Zeuli, K., Nijhuis, A., & Gerson-Nieder, Z. (2018a). *Resilient food systems, resilient cities: a high-level vulnerability assessment of Toronto's food system*. Toronto, ON. Retrieved from <https://www.toronto.ca/legdocs/mmis/2018/hl/bgrd/backgroundfile-118076.pdf>

Zeuli, K., Nijhuis, A., Macfarlane, R., & Ridsdale, T. (2018b). The impact of climate change on the food system in Toronto. *International Journal of Environmental Research and Public Health*, *15*(11), 2344. <https://doi.org/10.3390/ijerph15112344>

Ziska, L., Crimmins, A., Auclair, A., Garofalo, J. F., Khan, A. S., Showler, A., & Thurston, J. (2016). Food safety, nutrition and distribution. In A. Crimmins, J. Balbus, J. Gamble, C. Beard, J. Bell, D. Dodgen, … L. Ziska (Eds.), *The impacts of climate change on human health in the United States: A scientific assessment* (pp. 189-216). Washington, DC: U.S. Global Change Research Program.