CHAPTER 4: **FOOD PRODUCTION**

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Recommended citation:

Campbell, I.D., Durant D.G., Hunter, K.L. and Hyatt, K.D. (2014): Food Production; *in* Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON, p. 99-134.

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KEY FINDINGS

A changing climate presents Canadian food producers with a number of opportunities as well as risks that will challenge the food supply industry, particularly in the short term. Key findings include:

- Impacts of climate change differ significantly among the sectors discussed (agriculture, fisheries and non-commercial food supply), but common challenges did emerge, including threats to food supply from increased losses from invasive pests and diseases, and risks to the transportation systems upon which the sectors rely.

- The net medium-term outlook is for a likely modest increase in agricultural food production. Longer and warmer growing seasons would allow higher-value warmer-weather crops to be grown further north (where soil conditions permit), lengthen outdoor feeding seasons for livestock, and allow the maple syrup industry to expand northward. However, there will likely be new pests and diseases, as well as more severe outbreaks of current ones, increased growth of weeds, and other challenges that could negatively affect production and require timely adaptation (e.g. improved water efficiencies and changes in crop management practices).

- Northern and remote communities are likely to see great changes in their environment – some will ease food security concerns while others could exacerbate already decreasing country food stocks and difficulties in delivering supplies into isolated areas.

- Canada is expected to remain a net exporter of aquatic foods at the aggregate level, with total biomass of production from wild-capture fisheries in Canada expected to increase due to climate-induced shifts in fish distributions. Regional impacts from invading species, physical habitat changes and societal responses to shifts in availability and access to aquatic food resources will gradually determine future patterns of use and overall economic implications.

- Aquaculture has a greater scope for adaptation to climate change than other fisheries, making it less vulnerable and better positioned to take advantage of opportunities than capture fisheries, and subsistence fisheries in particular.

1. INTRODUCTION

Food production is a major economic driver in Canada, with the agriculture sector contributing $98 billion to our GDP in 2009 (AAFC, 2011) and exports of fisheries products valued at over $4.1 billion in 2012 (DFO, 2013a). The importance of reliable access to healthy and affordable food for Canadians also cannot be overstated. While food production is affected by many factors, including technological advancements, market forces, and food demand and preferences (e.g. for organic products), climate is also a key consideration. Food production on land and in water is inherently sensitive to climate.

Canada's food system is as varied as its geography. Food is produced and sourced through industry-based production of agricultural and fisheries products, as well as important country-food chains that involve non-commercial elements, including fishing, hunting, gardening and gathering. Food systems rely on responses by social mechanisms to manage environmental changes that affect food production and food security (Godfray et al., 2010; Ziervogel and Ericksen, 2010; Perry et al., 2010; 2012). This chapter focuses on the food production elements of Canada's food system.

Food production from agriculture relies mostly upon intensive culture and harvest practices at relatively fixed sites, where selectively cultured crops account for the bulk of food produced, making production highly dependent upon market conditions. In contrast, fisheries depend principally on highly mobile, wild harvest systems that are subject to environmental conditions that influence distribution and abundance of products. However, aquaculture, which has been increasing in Canada, does offer a system of producing aquatic foods that allows more predictable production schedules. These different contributors to the food systems face diverse impacts and challenges related to a changing climate (Figure 1).

This chapter discusses the implications of climate change for food production from agriculture, fisheries and other non-commercial sources (including hunting and gathering), focusing on observed and potential impacts. Adaptation is discussed, with additional details provided through case studies that highlight the challenges and vulnerabilities of food production in Canada's changing climate.

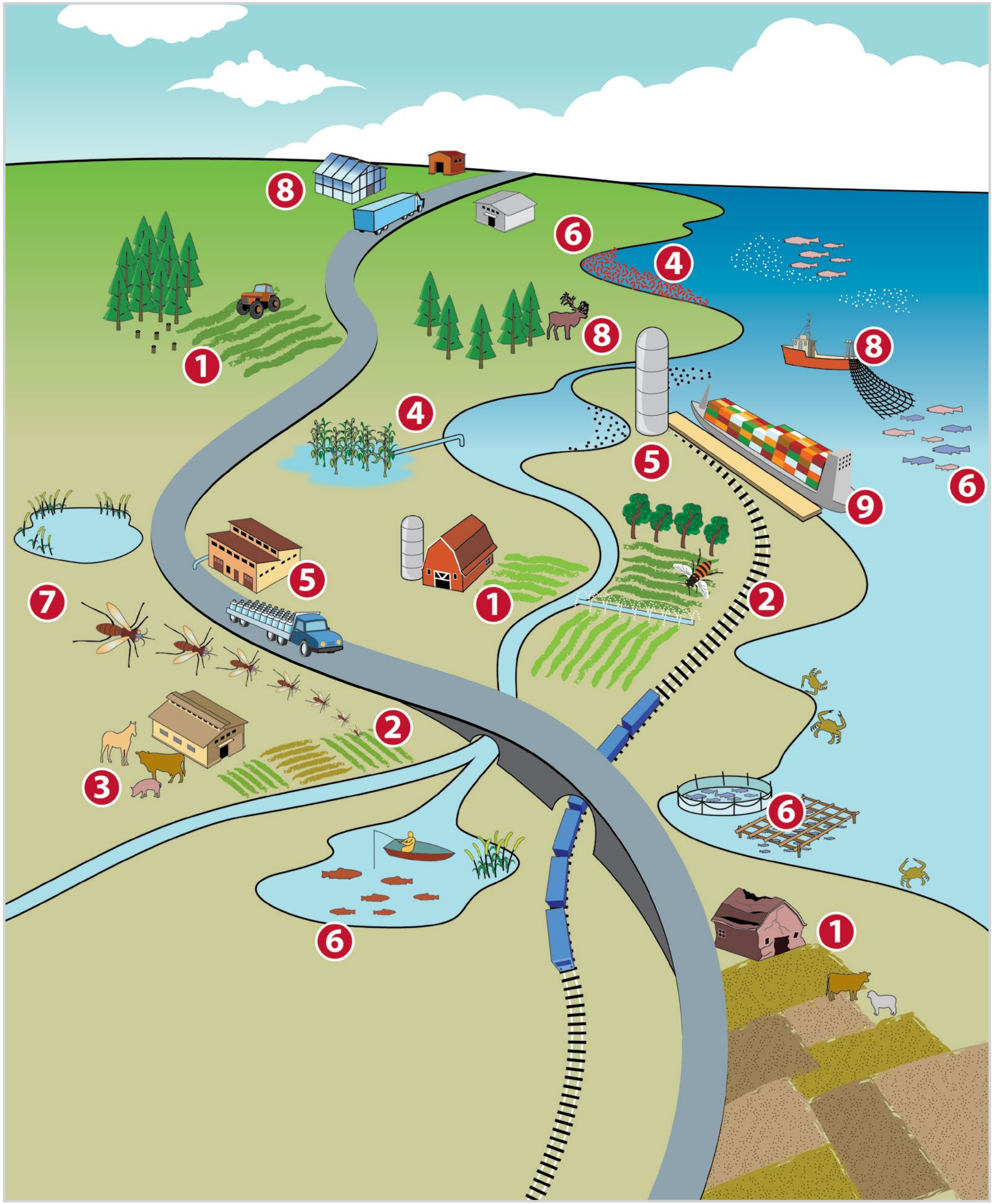

FIGURE 1: A summary of potential climate change effects on food production in Canada. 1) Crop productivity depends strongly and directly on seasonal weather for heat, light and water. Locations for particular crops will also change. 2) Pollinators would face shorter, less harsh winters but may be affected by increased pest and disease activity, different food sources and changes in the timing of flowering. 3) Animal production will be affected by changes in crop production, water availability and heating and cooling requirements. 4) Changes in water supply and precipitation patterns will affect farm operations (e.g. need for drainage or irrigation). Water quality will also be affected (e.g. increased flushing of contaminants into waterways due to heavy rainfall). 5) Food processing may be challenged by reduced or variable water availability. Food and feed storage will need to deal with increased heat, and in some places, increased storage capacity may be required to allow for increased frequency and duration of transportation interruptions. 6) Fish stocks will respond to changes in water temperatures, water chemistry, food supply, algal blooms, runoff and ocean currents. Reorganizations of lake/ocean ecosystems are likely, with resultant impacts on all types of fisheries. 7) Pests, diseases and invasive species could become more virulent and diverse. 8) Northern/remote communities may be able to increase local food production with adaptation (e.g. greenhouses, cold-tolerant field crops and forages). Access to country foods will be affected as vegetation is directly impacted by changing climate, and species distributions will shift in response to warming. Decreased ocean ice could increase the length of the shipping season, allowing more items to be brought to northern coastal ports. 9) International trade will be affected by the change in the global geography of food production with countries shipping new types of goods as well as by the potential opening of the Northwest Passage.

2. AGRICULTURE

2.1 INTRODUCTION

Canada, which has about 650 000 km^2 of farm area (~7.2 % of Canada's total land area, Figure 2; Statistics Canada 2012), was the fifth largest agricultural food exporting nation in 2010 (AAFC, 2011) and produces 70% of the food purchased in Canadian stores (Statistics Canada, 2009a). Canada has a wide diversity of agricultural landscapes capable of growing and supporting a large assortment of crops and livestock. The capacity for any area to sustain agriculture is dependent on several factors, including soil composition, water and land availability, temperature, pollinators, sunshine and snow cover.

Climate affects crop productivity, animal production, virility of pests and diseases, pollinator health and water availability and quality. Climate changes will necessitate changes in human activities (e.g. cropping systems, use of irrigation) and lead to flora and fauna reactions (e.g. northward movement). Plants, animals and humans need to adapt to changing conditions. This portion of the chapter outlines recent research findings relevant to climate change impacts and adaptation in the Canadian agriculture and agri-food sector.

2.2 ECONOMIC TRENDS AND CONTEXT

The agriculture and agri-food system accounted for 8.2% of Canada's GDP in 2009 (AAFC, 2011). Primary agriculture and food processing play a particularly key role in the economies of certain provinces, such as Saskatchewan and Prince Edward Island (PEI), contributing 12.8% and 10% to their provincial GDPs, respectively (Figure 3), while Ontario, Quebec and Alberta together accounted for almost 70% of the total Canadian agriculture and food processing

FIGURE 2: Map showing the agricultural extent of Canada *(Source: AAFC, 2013).*

GDP (Figure 4; AAFC, 2012e). This sector employs over 2 million people and accounts for the largest share of employment in both PEI and Saskatchewan (AAFC, 2011).

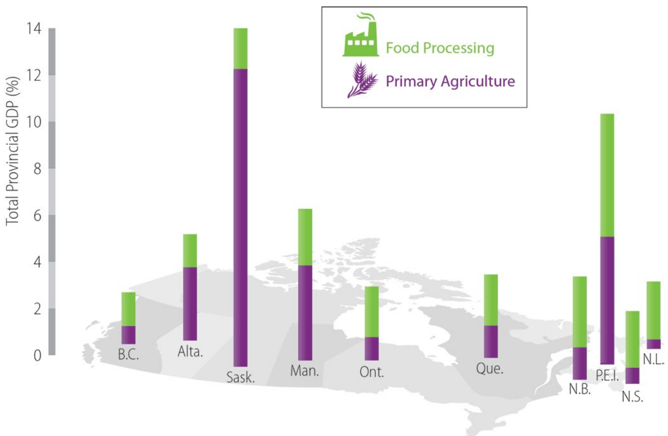

FIGURE 3: Contribution of food processing plus primary agriculture to provincial GDPs in 2011 *(modified from AAFC (2012e)*, chart B1.5). 2011 data is preliminary. Excludes beverage and tobacco processing.

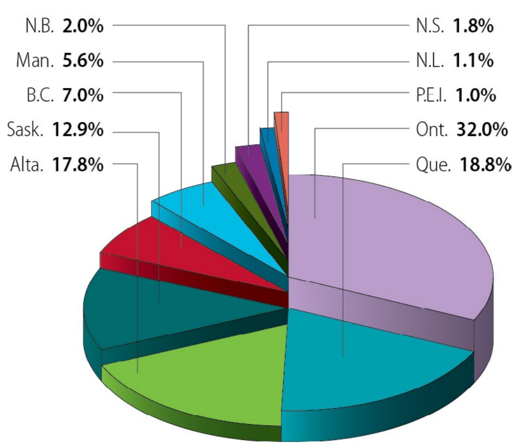

FIGURE 4: Distribution of agriculture and food processing contribution to the Canadian agricultural GDP *(modified from AAFC (2012e), chart B1.6)*.

Over the last 70 years, there has been consolidation in the sector with 732 800 farms in 1941 decreasing to 205 700 in 2011. While about 62% of farms currently gross under $100 000, the number of farms with gross receipts over $500 000 increased from 19 817 in 2006 to 23 579 in 2011 (Statistics Canada, 2012). Farms with revenues greater than $1 000 000 accounted for 20% of total operating revenues in 1994 rising to 50% in 2009 (AAFC, 2011). At the same time, farm debt has been steadily increasing (NFU, 2011). The data suggest that farmers are continuing to invest in land and equipment, as well as paying more into operating loans and input suppliers (NFU, 2011). The average age of farmers has also risen (Statistics Canada, 2012).

The types of commodities produced across Canada depend on many edaphic (e.g. soils, topography), climatic (e.g. length of frost-free season, precipitation patterns), socio-economic (e.g. consumer preferences, regulatory environments) and historic factors (*see*, for example, Clark, 2010). Figure 5 shows the distribution of commodities amongst farms, while Figure 6 shows the distribution across regions. The largest crops by total field crop area in 2011 were canola at ~22.5 % and spring wheat at ~20% of total farm area respectively (Statistics Canada, 2012). Crop-based farms accounted for 58.4% of farms while livestock-based farms comprised 41.6 % in 2011 (Statistics Canada, 2012).

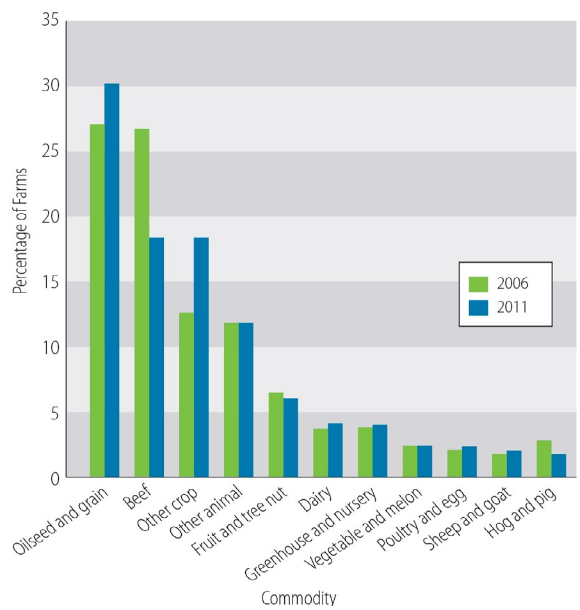

FIGURE 5: Percentage of farms by commodity for 2006 and 2011 *(modified from Statistics Canada, 2012)*.

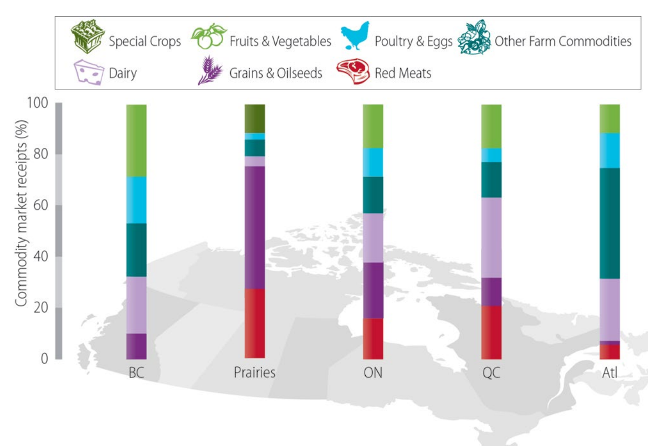

FIGURE 6: Commodity market receipts by region for 2009 *(modified from AAFC, 2011, Chart C4.6)*.

Another trend in agriculture is the increasing awareness of the importance of sustainable farming. Operations with completed environmental farm plans increased from 13% in 2001 to 35% in 2011 (AAFC, 2014). No-till farming, which can enhance soil health by reducing compaction and increasing carbon storage, water and nutrient infiltration, increased from less than 10% in 1991 to almost 50% of cropped land in 2006 (AAFC, 2011). Water quality is better protected by the increasing use of riparian buffer zones, controlled tile drainage and controlling livestock access to natural surface waters (AAFC, 2011). Greenhouse gas emissions from agriculture decreased by 2.6% between 1990 and 2007, largely due to changes in land use (AAFC, 2011). New or modified technologies and processes are creating more efficient machinery and practices that aim to decrease both on-farm costs and the impact of operations on the landscape.

The livestock sector has shown a downward trend in numbers of animals (e.g. hogs and beef cattle) due to a number of events, including restrictions in cattle exports, high feed prices and a strong Canadian dollar for hog exports (AAFC, 2013). Dairy cattle numbers decreased from nearly 1 800 000 in 1981 to 961 726 in 2011, even as total milk production has remained stable at around 7.5 million kilolitres (Statistics Canada, 2012) due to gains in efficiency (AAFC, 2013) through animal genetics, feed management and other practices (AAFC, 2011).

2.3 KEY FINDINGS FROM PAST ASSESSMENTS

Agriculture was addressed in most of the regional chapters of '*From Impacts to Adaptation: Canada in a Changing Climate 2007*' (Lemmen et al., 2008), generally as stand-alone sections describing a wide range of impacts (positive and negative), examples of current adaptation initiatives, and discussion of future adaptation options. Those chapters demonstrated that changes in temperature and precipitation regimes will have important effects on agriculture in Canada, intensifying existing risks, as well as presenting new challenges and opportunities. While all of Canada will be affected, the impacts will not be uniform across the different agricultural landscapes, with distinct issues for four regions: 1) Eastern and Central Canada; 2) Northern Canada; 3) Prairies; and 4) British Columbia.

EASTERN AND CENTRAL CANADA

(from Bourque and Simonet, 2008; Chiotti and Lavender, 2008; and Vasseur and Catto, 2008)

Increasing spring runoff will be a key challenge for this region, presenting concerns regarding flooding (potentially increasing field nutrient losses and surface water pollution) which could make it more difficult to complete spring seeding and other field operations. Increasing spring precipitation and higher intensity storms will also impact manure storage, increase runoff of livestock manure and soil nutrients from fields into riparian zones, and increase soil erosion. Adaptation could involve revising management practices and, in some cases, building runoff retention structures (including wetlands).

Increasing summer temperatures are expected to increase growing season length and allow some crops to be grown farther north, with some crops benefiting and others being negatively affected. Increased evaporation could cause water stress and potentially decrease productivity. Reduced water availability might be partially offset by increased water use efficiency by crops under higher CO_2 conditions. An increased likelihood of winter bud kill (especially fruit trees and vines) and the occurrence of more variable, late killing frosts could result in heavy crop losses, as could potential increases in agricultural pests, diseases and weeds.

Livestock operations can expect reduced heating and increased air conditioning needs, as well as more heat waves that will require adaptations such as adding more shade trees to pasture lands. While dry heat waves can decrease animal weight gain, reduce milk production, and reduce conception rates, warmer and wetter conditions can also negatively impact animal health as a result of increased numbers of ticks, mosquitoes, parasites and bacteria. However, livestock may benefit from warmer winters since they can be fattened longer outdoors.

NORTHERN AND REMOTE COMMUNITIES

(from Furgal and Prowse, 2008)

Climate change is affecting the availability and quality of wild foods such as berries, wild rice and game animals, all of which are key elements of country food systems. Food shipments to the north will be affected by a shorter ice-road season (a cheaper way to ship large bulk items to some northern communities). Reduced sea ice cover will result in a longer marine transport season that may benefit coastal communities with port facilities, although the effects of more intense storms and changing ice conditions need to be taken into account.

PRAIRIES
(from Sauchyn and Kulshreshtha, 2008)

Water issues present the greatest concerns for the Prairies. Reduced summer rainfall affects both groundwater quality and availability. Increased drought frequency and intensity, increasing demand to plant more high-value crops, greater demand from non-agricultural users (e.g. oil, gas and potash extraction) and the need to maintain river flows for aquatic ecosystems, may limit the ability to expand irrigated agriculture and livestock. Increased spring floods could increase soil nutrient losses and algae blooms in catchment basins.

While a warmer climate will likely lengthen the growing season, it will also reduce snow cover during winter, leading to less cover protection against soil erosion by winter winds. Increasing pests and diseases are also likely in a warmer climate, as southern organisms move north and northern organisms are less impacted by winter die-offs. Integrated plans and policies for holistic water management at the regional and watershed levels (e.g. capturing excess water for use during droughts) may need to be revised or developed.

BRITISH COLUMBIA
(from Walker and Sydneysmith, 2008)

Reduced summer stream flows, reduced groundwater recharge and increasing demands for water from other sectors will challenge water resource management for agriculture. Agriculture in the Okanagan Valley is already heavily dependent on irrigation, and increasing temperatures and longer growing seasons will mean higher crop-water demands that existing infrastructure may be unable to meet. In coastal regions, sea level rise could cause saltwater intrusion into aquifers as well as coastal inundation of farmland, resulting in a loss of farmland and decreased quality of drinking and irrigation waters.

Increased heat could bring a higher risk of pests, fires and summer drought, which can impact fragile wineries and orchards and affect agri-tourism. Shifts in climate could permit the growth of cereals and potatoes in the interior, along with corn and tomatoes, as far north as Prince George. Adaptations currently in use, such as wind machines to offset late frosts in orchards and wineries, evaporative cooling by irrigation to offset crop heat stress, water licensing for water use to reduce waste, and processes for pest management will need to be adjusted to deal with changing conditions.

2.4 RISKS, OPPORTUNITIES AND ADAPTATION

This section discusses the many different risks and opportunities that the Canadian agriculture sector faces from a changing climate, focusing on new findings.

2.4.1 LAND SUITABILITY FOR CROPS

The Land Suitability Rating System (LSRS) assesses the climate, soil and landscape characteristics of an area to derive a suitability class rating for the production of a specific crop (AAFC, 2012a). The final land suitability class is based on the most limiting of these factors (climate, soil or landscape). Suitability is expressed in a 1 to 7 rating system where Class 1 has no significant limitations for production of a specific crop and Class 7 is unsuitable for agriculture (Agronomic Interpretations Working Group, 1995). Table 1 describes the severity of limitations associated with each suitability class and groupings of classes for the assessment of potential differences due to climate, soil or landscape.

Suitability Class	Description	Groupings of suitability classes
Class 1	Land in this class has no significant limitations for production of the specified crops	None to Moderate Limitations
Class 2	Land in this class has slight limitations that may restrict the growth of the specified crops or require modified management practices	
Class 3	Land in this class has moderate limitations that restrict the growth of the specified crops or require special management practices	
Class 4	Land in this class has severe limitations that restrict the growth of the specified crops or require special management practices, or both. This class is marginal for sustained production of the specified crops	Severe Limitations
Class 5	Land in this class has very severe limitations for sustained production of the specified crops. Annual cultivation using common cropping practices is not recommended	
Class 6	Land in this class has extremely severe limitations for sustained production of the specified crops. Annual cultivation is not recommended, even on an occasional basis	Not Suitable
Class 7	Land in this class is not suitable for the production of the specified crops	

TABLE 1: Land suitability classes for spring seeded small grain (SSSG) crops *(Source: AAFC, 2012a)*.

Hewitt et al. (2008) used the LSRS system to present current (1971-2000) and projected agricultural land suitability (2010-2039 based on the A2 and A1B SRES scenarios) for spring seeded small grain (SSSG) crops on the Canadian Prairies (Figure 7). The significant changes in LSRS ratings between 1971-2000 and 2010-2039 were then calculated and mapped for the current (2011) agricultural regions of Western and Eastern Canada (Figures 8 and 9, respectively), using the assumption that climate was the only factor that changed through time.

The analysis suggests that the greatest potential improvement for SSSG crops is in western Alberta and northeastern BC, where 5.3% of the land shown could improve. Only a very small amount of land (0.4%), shows decreased potential, primarily on the eastern Prairies and in southern Ontario.

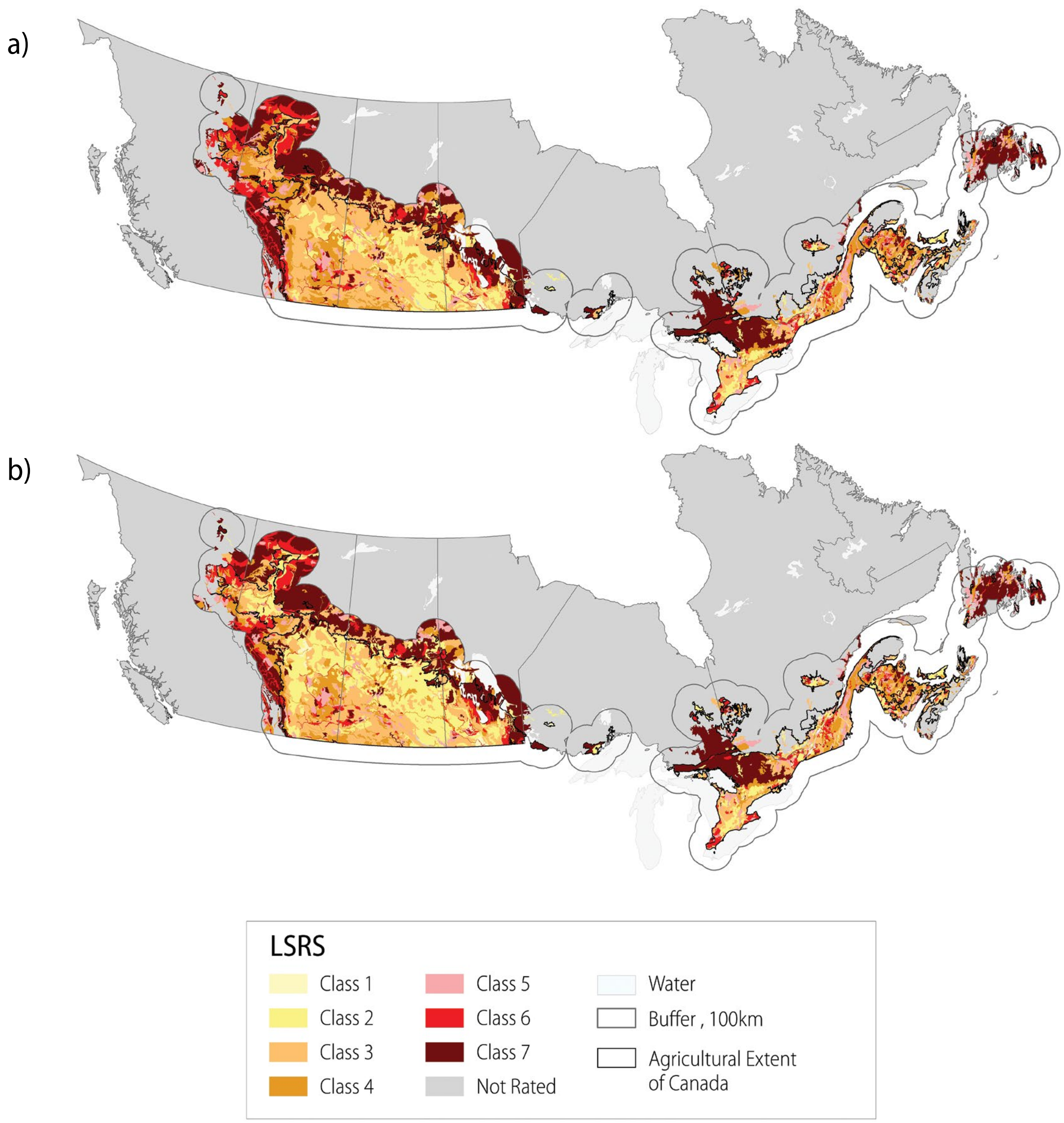

FIGURE 7 (a, b): Map of land suitability for spring seeded small grain (SSSG) crops based on climate data for **a)** 1971-2000 and **b)** a scenario of projected land suitability based on modeled climate data for 2010-2039, as prepared by AAFC (2012a) using Hewitt et al. (2008) methodology and updated Soil Landscapes of Canada (SLC) spatial data (Schut et al., 2011). Note: the southern and central areas of British Columbia were not included in the figures because the modelled climate data was at too coarse a resolution to accurately represent the climate in the valleys where agricultural production could occur.

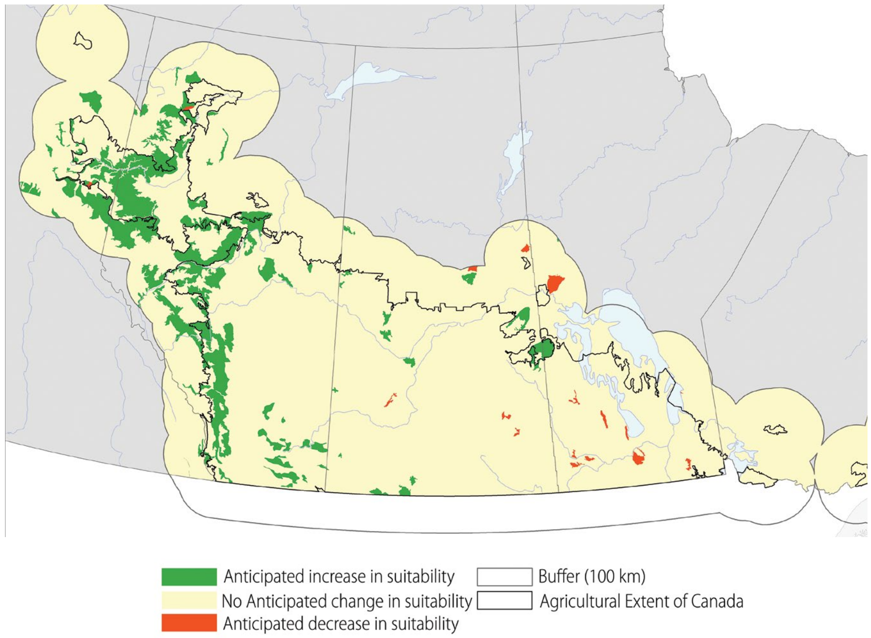

FIGURE 8: Map of Western Canada showing projected significant improvement and decline in land suitability for spring seeded small grain crops *(Source: AAFC, 2012a)*.

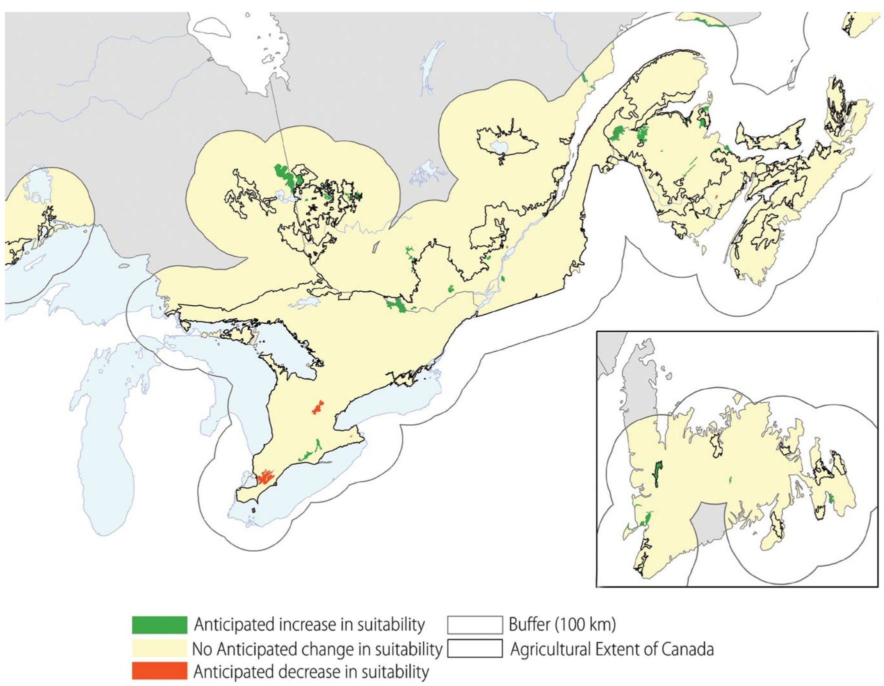

FIGURE 9: Map of Eastern Canada showing projected significant improvement and decline in land suitability for spring seeded small grain crops *(Source: AAFC, 2012a)*.

The modelling supports other analyses that indicate a likely increase in potential land for SSSG crops into some areas that are further north, and into areas that are now primarily hay and forage. The modelling also shows that potential for SSSG crops in dry areas could remain the same or increase slightly, assuming that producers seed earlier in order to decrease exposure to drier late summer conditions (AAFC, 2012a).

2.4.2 CROPS/CROPPING SYSTEMS

A literature review by Kulshreshtha et al. (2010) identified uncertainties in yield predictions, implying that crop productivity could either increase or decrease in a changing climate. Some of the uncertainty was attributed to studies not considering indirect effects of climate change on pests, diseases and weeds and other factors that influence crop production, such as soils (Wheaton and Kulshreshtha, 2009). Uncertainties in yield projections also include gaps in our current understanding of climatic variability, including how various teleconnections such as the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO) currently interact and how these interactions could be impacted by future climate change (Reuten et al., 2012; *see also* Box 1).

While production of new crops may be agronomically feasible, there are uncertainties as to whether producers would be able to adapt their operations in a timely manner, due to factors such as financial constraints (Kulshreshtha et al., 2010), uncertainties in government policy and programs (Pittman et al., 2011) and increased variability in climate (*see* Box 1). Producers will also need to balance changes to a number of shifting variables. For example, early July temperature and precipitation conditions are critical for canola yield; higher maximum temperatures negatively affect yield, and higher than average precipitation positively affects yield (Kutcher et al., 2010).

Future climate scenarios for the Canadian prairies may favour increased use of pulse crops in rotations, including the increased use of fall seeded pulse crops (Cutforth et al., 2007). Chickpea and lentil cultivars are suited to climatic extremes of frost and drought, for example, as they require physiological stress (e.g. by drought) to terminate flowering and induce seed set (Saskatchewan Pulse Growers, 2000). In response to warmer and longer growing seasons, soybean production may shift northward into Saskatchewan and other parts of the Prairie region (Kulshreshtha, 2011) and conditions may become more suitable for corn production on the prairies. Sorghum could be well suited to new climate conditions since it produces an extensive root system early in its development and closes its stomata quickly when faced with increasing water deficit (Almaraz et al., 2009). Adaptation practices that protect crops from wind damage and high evaporative loss, such as stubble contouring and reduced tillage, will become even more important tools in prairie crop management (Cutforth et al., 2007).

In British Columbia, seasonal and spatial patterns of projected warming and increases in precipitation (*see* Crawford and McNair, 2012; Zwiers et al., 2011; and Chapter 2 – An Overview of Canada's Changing Climate) would allow more options for cropping, and potential benefits for grazing and livestock operations. However, warmer, drier summers can increase susceptibility to drought, and wetter autumns can pose an increased risk to harvesting success. A projected increase in growing degree days in the valley areas surrounding Prince George by the 2050s would make the climate conducive to growing canola and other crops that previously could not have been grown in this area (Picketts et al., 2009).

BOX 1

CLIMATE VARIABILITY – A KEY CHALLENGE FOR PRODUCERS

Farming as an annual undertaking depends heavily on seasonal weather, but as an industry and business, it depends more on the inter-annual predictability of seasonal weather. A farmer who knows the range of conditions that will be faced over a period of years can select crops, practices, and infrastructure investments that will allow profit to be drawn from those conditions. It is the unpredictability of conditions that causes farm losses. A major difficulty in assessing agroclimate under climate change scenarios is therefore our incomplete understanding of current climate variability (Reuten et al., 2012), and the expectation that future climate will be not just warmer, but more variable. Recent progress in understanding multi-decadal cyclic patterns in atmospheric pressure–ocean current relationships such as the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), the Atlantic Multi-decadal Oscillation (AMO), and the sub-decadal El Niño-Southern Oscillation (ENSO) has helped explain some of the climate variability in Canadian agricultural areas (Perez-Valdivia et al., 2012, Reuten et al., 2012). However, to better project the future variability of agroclimate, a better understanding of how and to what degree climate change will interact with these short and long cycle teleconnections is needed.

Over the past three decades, Quebec's Montérégie region has seen a general trend of increasing temperature, with the greatest change in the growing season occurring in September when mean temperatures have increased by 0.8°C (Almaraz et al., 2008). The warmer and longer growing season will benefit corn, soybean and forage productions (Ouranos, 2010). The cultivation of corn and soybeans might extend into new regions with the appropriate soil and topography, such as Saguenay-Lac-Saint-Jean, Abitibi and Bas-Saint-Laurent–Gaspésie (Ouranos, 2010). Maple syrup production in the region will also be affected (*see* Case Study 1).

2.4.3 PESTS, DISEASES AND INVASIVE ALIEN SPECIES

Many agricultural pests and diseases are climate-sensitive, and are expected to respond to climate change with changes in the frequency, severity and distribution of outbreaks (Aurambout et al., 2006; Gagnon et al., 2011; Gagnon et al., 2013; Luck et al., 2014). The impact on food production is difficult to predict, in part because the climatic ecology of many of these pests and diseases is poorly understood, and in part because the severity of losses due to these pests and diseases will be a function not just of their ecology, but also of decisions made around pest and disease control, crops and agricultural practices, and other management decisions

CASE STUDY 1

MAPLE SYRUP AND CLIMATE CHANGE

Maple syrup is a quintessential Canadian product – thanks to a warming climate. A century ago, some 80% of the world's maple syrup was produced in the United States (USA) and 20% in Canada. Today Canada produces about 85% of the world production of maple syrup (AAFC, 2007), with Quebec accounting for 90% (7.7 million gallons) of Canadian production in 2011 (Statistics Canada, 2011).

Northern USA tree species such as the sugar maple are moving north at nearly 100 km per century, with significant movement since 1971 (Woodall et al., 2009). Projections to 2100 for sugar maple range movement in Quebec (Duchesne et al., 2009) and in Ontario (Lamhonwah et al., 2011) show continuing northward movement, although the movement into northern Ontario will be slowed by poorer Canadian Shield soils (Lamhonwah et al., 2011). Many US states have reported that syrup seasons are starting and finishing earlier, that temperature can be too warm to get full production and that the syrup collected is of lower grade with less sugar (USDA, 2012).

Optimal temperatures for the maple sugaring season are -5 °C at night and +5 °C by day for the sap to flow in economically viable amounts (AAFC, 2007; Figure 10). With this temperature range moving north, Canada has gained a much larger part of the industry. With sap flow days moving forward, possibly by as much as 30 days by 2100 (Skiner et al., 2010), start times for tapping trees will need to be adjusted, assuming that the trees are able to adjust to earlier flow times (Duchesne et al., 2009). Planned adaptation could involve investing and installing new, more efficient collection systems that have been shown to increase yield, and increasing quotas in order to allow more new taps to make up for shortfalls (Duchesne et al., 2009).

FIGURE 10: Maple sap collection is moving northward as temperatures warm *(Photo © 2007, Her Majesty the Queen in Right of Canada, as represented by the Minister of Agriculture and Agri-Food).*

(Luck et al., 2014). Examples of adaptation measures include earlier detection of pests to better target dates for intervention, the provision of cultivars and integrated pest management tools adapted to the new climate conditions and the development of a sensing network for emergence of new pests (Comité de suivi et de concertation de la stratégie phytosanitaire québécoise en agriculture, 2011; Gagnon et al., 2013). Arguably, the impact on agriculture of new invasive alien species presents greater risks, as there is ongoing research and/or mechanisms in place to manage pests and diseases that are currently present. However, many of the new pests and diseases that could enter Canada due to climate change are already present elsewhere (particularly in the United States) where there may be knowledge to draw from, and control processes in place, that could be adapted and used in Canada (*see*, for example, Case Study 2).

Potential ranges of some climate-sensitive pests and diseases of significance to agriculture have been estimated (e.g. Baker et al., 2000; Aurambout et al., 2009), particularly for invasive alien species, the presence of which can affect international trade through the sanitary and phytosanitary provisions of the WTO. Several countries including Canada are considering how biosecurity policies may need to adapt to climate change and are studying climate change impacts on invasive alien species (Luck et al., 2014). The pest risk assessment process, as currently practiced, involves mapping an organism's current known range against basic climate parameters, which are then used to project the potential range in case of establishment in a new country. Canada and several other countries are using climate scenarios to examine potential future weed and pest distributions (Luck et al., 2014).

In Canada, entry of invasive alien species will increase with increased trade globalisation associated with climate change and other economic and political factors (IPCC, 2007). Potential changes in trade routes, for example the opening of the Northwest Passage, may also alter the risk of introductions (Luck et al., 2014).

The effects of increasing atmospheric CO_2 on plant pests and diseases are uncertain; in some cases pest activity may increase or plant hosts may become less resistant, while in others, plant hosts may become more pest resistant and pathogenic (e.g. Chakraborty and Datta, 2003; Fuhrer, 2003; Chakraborty, 2005; Coll and Hughes, 2008).

CASE STUDY 2

BLUETONGUE: PRIVATE SECTOR AND GOVERNMENT ADAPTATION TO THE POTENTIAL CLIMATE-CHANGE DRIVEN SPREAD OF AN ANIMAL DISEASE

Bluetongue is a viral disease of ruminants, sometimes fatal to sheep but rarely fatal in other animals and not contagious to humans. It is carried by a number of species of midges and could result in closure of export markets. It is not yet believed to have become established in Canada; a handful of Canadian cases are believed to have been due to mites accidentally imported from the United States (Lysyk and Danyk, 2007).

In North America, bluetongue is carried mainly by a species of midge whose Canadian range extends into British Columbia, but not into other provinces at this time. The Canadian Food Inspection Agency (CFIA), the government agency responsible for monitoring such animal diseases, has pre-emptively established five ecologically based regions in Canada for bluetongue control, in the hope that should bluetongue occur in one of those regions, our trading partners will recognize that not all Canadian ruminants are potentially exposed, and trade in animals and products from the other regions will not be affected (CFIA, 2011).

Another pre-emptive adaptation for possible future bluetongue incursions has been implemented by the Canadian Sheep Federation: bluetongue insurance. This voluntary insurance program will compensate insured sheep farmers for loss of animals, business interruption and other consequential losses in the event one of their animals is found to have bluetongue (www.cansheep.ca/cms/en/programs/bluetongueprogram/bluetongueprogram.aspx).

This example highlights several aspects of climate change adaptation for agriculture in Canada, including the proactive response by a government agency and the pre-emptive response by the industry.

2.4.4 ANIMAL ISSUES

Livestock management will need to adjust to higher temperatures, shifts in precipitation patterns and adaptation in the cropping sector (Pullar et al., 2011). Livestock producers are keenly aware of the need to increase efficiencies in their operations and reduce their environmental footprint. For example, higher quality feed means less emissions (less gas and manure), higher productivity (more offspring, dairy, eggs) and healthier animals (less susceptible to stress events) (Pullar et al., 2011).

For the dairy industry, great strides have been made in increasing the efficiency of operations. The number of dairy cattle has decreased some 47% while total milk production has remained stable (milk production per cow has increased by 48% from 1981 to 2011; Statistics Canada, 2012). While much of the increased productivity is attributed to genetic selection (Oltenacu and Broom, 2010), the ability of the sector to remain profitable with half the number of cattle suggests producers have strong adaptability capacity, and will be able to adapt farm infrastructure to changing climate conditions.

With the likely increase in crop-growing season length, McCartney et al. (2009) examined the potential in Canada for using warm-season, late-standing crops as feed for cattle. They found that while it could be possible to use residues of corn, sorghum, millet, rape, and turnips and other root crops, there are many caveats, such as the health of the plants, pesticides that were used on the crops, toxins in soils from droughts or floods and nutritional value of the stalks (McCartney et al., 2009). Furthermore, higher annual temperatures would allow producers to consider planting previously unsuitable perennial pastures and winter annual crops. Annual cereals have more flexibility than perennials with respect to planting dates. If planted later, they will produce later seasonal peak yields that can be used to supplement winter pastures (McCartney et al., 2008).

Provincial strategies for climate change adaptation are being implemented that require producers, as well as governments, to consider the effects of climate change on livestock. For example, the Government of Ontario formed a formal partnership with the Animal Health Laboratory at the University of Guelph to support the detection and surveillance of animal diseases, including those that are emerging and evolving as a result of climate change (MOE, 2011).

British Columbia's *Climate Change Adaptation Risk and Opportunity Assessment* (British Columbia, 2012) outlines potential climate change impacts on livestock from climate change, including: changes to livestock grazing management due to too little or too much soil moisture; loss or relocation of livestock due to flooding and other extreme events; reduced water quality and quantity for livestock during dry conditions; warmer winters that could allow diversification of livestock; increased survival of diseases and pests; increasing energy costs due to increased ventilation needs; higher land costs due to increasing pressure on land value as population rises in southern BC; and power outages due to increased frequency of storms and blizzards that affect operations (British Columbia, 2012). Work to date includes a series of regional reports highlighting actions to be undertaken, as well as decision-support tools, such as new irrigation calculators (IIABC, 2009).

In a warmer climate, grassland productivity is expected to increase not only from the longer, warmer growing periods but also because of enriched CO_2 environments. Responses of forage crops to climate change are species-specific and there are complex interactions between atmospheric CO_2 concentration, temperature, and species (Bertrand et al., 2012). In addition to affecting the yield, future climatic conditions are likely to impact the nutritive value of forages (Bertrand et al., 2012). Increased pasture productivity would increase pasture carrying capacity and reduce cost per animal (Kulshreshtha, 2011). Grassland management, feed management, and use of agroforestry (shelterbelts) have been recommended as possible adaptations to climate change on livestock farms (Climate Change Connection, 2009).

2.4.5 EXPORT/GLOBAL MARKET ISSUES

The effects of climate change will vary across Canada and around the world. Risks for some will mean opportunities for others; higher food prices will promote greater investment to produce more food and could result in more spin-off industries such as local seed enterprises (FAO, 2009) and possibly further aquaculture development. However, higher prices mean less choice and reduced access for those with lower incomes. In international trade, agri-food excluding seafood accounted for more than $36 billion of Canadian exports in 2011, more than 8% of Canada's total merchandise exports (AAFC, 2012b). Wheat, canola, canola oil, and pork together accounted for more than $14 billion in exports (AAFC, 2012c). In all, agri-foods contributed more than $9 billion to Canada's trade balance (AAFC, 2012b). While increasing temperatures and CO_2 are likely to increase productivity, the effects of negative factors such as reduced water availability, weeds, pests, diseases, invasive species, and extreme weather events are unclear. Furthermore, the effects of climate change on many of our trading partners and competitors are also uncertain. The IPCC estimates that most developing countries will become increasingly dependent on food imports (IPCC, 2007). Given that Canada is one of the world's largest net exporters of agricultural products (WTO, 2000), this likely means increased opportunities for Canadian exporters.

Climate change will affect international trade in foodstuffs in other ways as well. The possible opening of the Northwest Passage may significantly reduce shipping times between North Atlantic and North Pacific nations, increasing trade in fresh produce within the northern hemisphere (Luck et al., 2014). Changes in locations of food production and consumption will also affect international trade, as will the risk of invasive alien species introductions (*see* section 2.4.3).

2.4.6 INSTITUTIONAL ADAPTATION

Agricultural practices are continually adapted to cope with climatic variability. Successful agricultural adaptations have historically been achieved with the collaborative efforts of numerous institutions (*see* Case Study 3; Marchildon et al., 2008; Diaz et al., 2009; Hurlbert et al., 2009a; Wheaton and Kulshreshtha, 2010; Corkal et al., 2011). Successful future adaptation for agriculture is likely to require similar multi-disciplinary and inter-disciplinary approaches with the active engagement of stakeholders and institutions that can help coordinate action (e.g. boundary organizations) (Diaz and Rojas, 2006; Batie, 2008; Marchildon, et al., 2008; Hurlbert et al., 2009b).

Institutional arrangements, involving all orders of government working in collaboration with producers, ranchers and other local stakeholders, and using multi-disciplinary and participatory planning approaches to integrate local and scientific knowledge, can assist in addressing current and future climate risks (Nelson et al., 2008; Hurlbert et al., 2009a, b; Corkal et al., 2011). Such adaptive governance can facilitate new technologies, strategies and collaboration, as well as test solutions to local problems, as long as institutions, farmers and local communities can be flexible enough to make the changes necessary to jointly define and solve a shared problem (Nelson et al., 2008; Hurlbert et al., 2009a, b).

Academic and government institutions are undertaking research to better understand climate variability and risk related to agriculture. These include studies that link scientific and local knowledge and inform water management decisions (Marchildon, 2009b; Sauchyn et al., 2010). In turn, watershed groups are encouraging the adoption of improved management practices, such as improved cropping and water management, including irrigation (Diaz et al., 2009).

At the international scale, Canada participates in the Global Research Alliance on Agricultural Greenhouse Gases (GRA), a multinational effort to stimulate and share research in the area of greenhouse gases and agriculture, with an emphasis on technologies and practices that give rise to reductions in greenhouse gas emissions along with increases in climatic resilience and profitability (Shafer et al., 2011).

Examples of federal government policies and regulations which could enhance climate resilience in the agricultural sector include the Livestock Tax Deferral provision which is invoked for areas affected by droughts or floods where producers have been required to sell at least 15% of their breeding herd. Percentages of proceeds from the sale can be deferred as income to the next tax year and may be used to partially compensate for the cost of replacing livestock (CRA, 2011). The Growing Forward 2 (www.agr.gc.ca/growingforward2) policy framework includes business risk management programs and tools, along with three new cost-shared programs to help increase economic sustainability for the agricultural sector. These regional and industry-led programs are designed to address needs in the sector through research, development and knowledge/technology transfer to ensure that innovative solutions are developed for producers in changing market and environmental conditions.

2.5 SUMMARY

The agriculture, agri-food, and agri-processing sectors will be affected by climate change in different ways and a diverse range of adaptation techniques will be needed. Innovative research and development, new and updated policies, and adaptive management of farm resources would help to promote an economically sustainable sector in the future..

CASE STUDY 3

HISTORICAL EXAMPLE OF INSTITUTIONAL CAPACITY FOR ADAPTATION IN THE AGRICULTURAL SECTOR – THE PRAIRIES

In his 1860 report, Captain John Palliser mapped what is now known as Palliser's Triangle after he observed the Prairies during a sustained drought period (Encyclopedia of Saskatchewan, 2007; Axelson et al., 2009). The population in Palliser's Triangle grew rapidly through to the early 1900s, during a wet period – as inferred from proxy tree-ring data during the last 1000 years (Sauchyn et al., 2011). These primarily European settlers did not understand the natural characteristics of the prairie region and were ill-prepared for climate risks from extreme temperatures, strong winds, drought and flooding in this region (Gray, 1996; Marchildon et al., 2008; Toth et al., 2009).

Multi-year droughts during 1914-17 and the 1920s-30s (Figure 11) were devastating to the region's people and ecology, the agricultural sector, rural communities and provincial and federal economies. During the "Dirty Thirties" great tracts of land were lost to soil drifting from wind erosion. De-population of the most affected areas occurred when farmers decided they could no longer survive on their land and began abandoning their farmsteads.

FIGURE 11: Drifting soil along fence lines meant loss of top soil in Prairie fields *(Photo is from the Library and Archives Canada collection R194-117-1-E PA-139647).*

Local, provincial and federal governments faced a social, economic and ecological crisis of national significance (Gray, 1996; Marchildon et al., 2008; Marchildon, 2009 a, b; Toth et al., 2009). Citizens and governments were forced to establish new institutional arrangements to better understand the problem, seek solutions for agricultural economic viability, and to strengthen rural community resilience and regional capacity to deal with soil conservation, water management, and sustainable farming practices.

In 1935 (just after the most damaging drought years), the federal government established the *Prairie Farm Rehabilitation Act*, and eventually created the Prairie Farm Rehabilitation Administration (PFRA) with a mandate to "secure the rehabilitation of the drought and soil drifting areas in the Provinces of Manitoba, Saskatchewan and Alberta, and to develop and promote [. . .] systems of farm practice, tree culture, water supply, land utilization and land settlement that will afford greater economic security" (Marchildon, 2009a; Justice Canada, 2012). Farmers and the farm industry worked together to develop innovative new farm implements. Research on farm methods and equipment design was undertaken by Agriculture Canada's Dominion Experimental Farms, universities, and industry. Drought-tolerant crops and new farming methods were researched and field-tested. The province of Alberta created the Alberta Special Areas Board to administer land in a region known as the Alberta Dry Belt, a particularly climate-sensitive area (Gray, 1996; Marchildon et al., 2008).

From the 1930s to 1980s, institutions and farmers worked hard to improve agricultural resilience. Sensitive lands were taken out of production by converting farmland to permanent grass cover or government-managed community pastures. Tillage practices were modified to involve less ground disturbance in an effort to conserve soil and soil moisture. These "minimum tillage" and "direct seeding" practices required new equipment designs which were developed and refined by industry and academia. This adaptation has now become common practice worldwide. Significant institutional efforts were deployed to develop water supplies with the construction of dams, reservoirs, extensive irrigation projects, and water distribution systems (Gray, 1996; Bruneau et al., 2009). The federal and provincial governments of Alberta, Saskatchewan and Manitoba created the Prairie Provinces Water Board to administer and monitor inter-provincial waters (Hurlbert et al., 2009a).

These collaborative institutional efforts are an example of past "institutional adaptations" that not only reacted to an initial situation but were also able to anticipate changes and develop solutions for the future. Today's prairie provinces, once considered as unsuitable for agriculture by Palliser, produce the majority of Canada's $7 billion production of cereal crops (Environment Canada, 2004; Corkal and Adkins, 2008).

3. FISHERIES

3.1 INTRODUCTION

Fisheries are an important contributor to food production that will be increasingly impacted by a changing climate (Barange and Perry, 2009; Rice and Garcia, 2011). Statistics Canada (2009b) reports that an average of 8 kg of fish (edible weight) per year is consumed by Canadians from retail sources, which translates to approximately 2.2% of national food expenditures (Statistics Canada, 2001). Food trends in Canada suggest that there has been a steady increase in demand for fish and shellfish since the mid-1990s and this increase is expected to rise by over 30% by 2020 (AAFC, 2012d). Changing tastes, healthier eating, availability of culture-fishery products and the appearance of new species at the fish counter are noted as important changes that relate to dietary trends (Statistics Canada, 2005).

Canada's fisheries reflect a diversity of area-specific interactions among climate, hydrology, oceanography, species assemblages, fisheries infrastructure and history of resource use (Figure 12). Climate change impacts on species and ecosystems have cascading effects on fisheries and interrelated human systems (i.e. food systems, cultural and social systems) that rely on aquatic food supplies. The degree of impact will depend on the magnitude of local climate change, the vulnerability of fish and fisheries, and adaptive responses.

This section discusses climate impacts on present and future aquatic food production systems in four major ecoregions (Figure 13, *see* Box 2). Climate change impacts on land-based elements of the aquatic food system (i.e. transport, processing, marketing) are addressed in a detailed case study from the Atlantic ecoregion (*see* Case Study 5). Cumulative effects resulting from multiple stressors on fisheries (i.e. climate and fishing; *see* Frank et al., 2005; Planque et al., 2010); non-renewable resource exploitation, cultural and social change; (*see* Meltofte, 2013); and contaminants (*see* Chapter 7 – Human Health) are not addressed in this chapter.

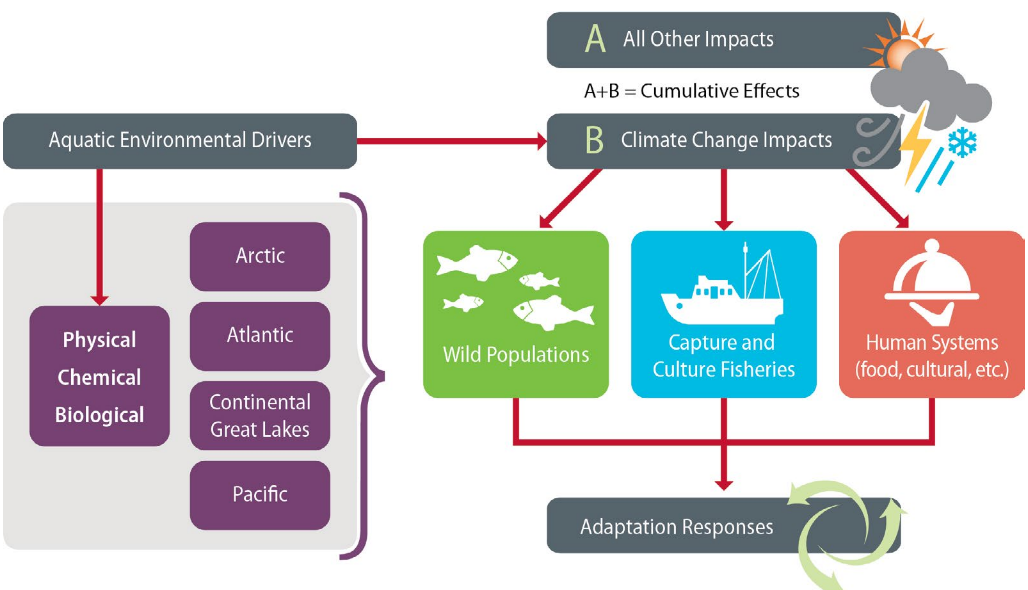

FIGURE 12: Pathway of climate change impacts on aquatic food production applied to Canadian aquatic ecoregions.

BOX 2

CANADA'S AQUATIC ECOREGIONS

ATLANTIC – The Atlantic ecoregion is characterized by cold winters, moderate-relief topography, a broad continental shelf and freshwater inputs. Atmospheric forcing affects continuous mixing of the warm, southern Gulf Stream with seasonal inputs of cool and fresh water, as well as sea ice, from the sub-polar Labrador Current and Gulf of St. Lawrence outflows respectively (Loder et al., 1998; DFO, 2012a). Near-surface temperatures are sensitive to seasonal variations in solar insolation, atmospheric temperature, freshwater run-off and strong current systems. Persistent multi-decadal shifts in the ocean climate of the region are influenced by the North Atlantic (NAO) and Atlantic Multidecadal (AMO) Oscillations (Reid and Valdés, 2011). Marine waters exhibit very high secondary production that supports large commercial capture fisheries (Shackell and Loder, 2012). Effects of fishing (Planque et al., 2010) and a cool-phase ocean state (Drinkwater, 2009) have had negative impacts on important groundfish populations.

ARCTIC – Defining features are a historically ice-dominated but rapidly changing area (Carmack et al., 2012) that includes an abundance of aquatic habitats which support a specialized assemblage of cold-adapted, late-maturing, resident (e.g. arctic char, walrus) or highly migratory species (e.g. bowhead whale, seabirds). Aquatic ecosystems experience very strong seasonality in sunlight, temperature and freshwater inputs. Ice cover is an important physical feature, affecting heat exchange and light penetration. Areas covered continuously by multi-year ice are generally not productive. However, areas of seasonally-recurrent open water amid sea ice (polynyas) provide critical habitat for a variety of organisms (e.g. under-ice algae, Arctic Cod, seals) and are often described as areas of enhanced productivity (DFO, 2012b). Ice is an important structuring agent influencing both ecosystems (e.g. mammal migrations, foraging locations) and associated human systems (e.g. seasonal travel and access to natural resources). Recent unstable summer ice conditions, ice retreat and altered freshwater input are inducing significant changes in Arctic aquatic ecosystems (Meltofte, 2013).

CONTINENTAL-GREAT LAKES (CGL) – This ecoregion forms the largest freshwater system on earth and contains 84% of North America's fresh surface water. CGL ecosystems are driven by continental climate systems that produce warm summers and cold winters during which most rivers and lakes are variably ice-bound. Variations in precipitation lead to annual- to decadal-scale "flood" or "drought" regimes. The latter, combined with strong seasonality, greatly influence river flows, lake surface elevations, nutrient cycling and biological production. Activities associated with more than a century of rapid human population increase have facilitated at least 162 aquatic alien species invasions (Mandrak and Cudmore, 2010) that are associated with many negative changes to CGL ecosystems and fisheries, along with the creation of some new fisheries (e.g. Chinook salmon, rainbow smelt). Modeling exercises suggest future climate change impacts in this ecoregion will result in changes to aquatic thermal regimes with negative consequences for cold- and cool-water species.

PACIFIC – The Pacific ecoregion is characterized by a moderate climate, mountainous topography, a narrow continental shelf, many rivers, heavy annual precipitation and a marine transition zone that is variably dominated by conditions associated with either sub-tropical or sub-arctic marine systems (Thomson, 1981). Ocean currents and discharge from major rivers greatly influence circulation, nutrient delivery and primary production of Pacific coastal marine ecosystems. Variability of physical, chemical and biological properties of Pacific coast ecosystems is amplified by the occurrence of sub-decadal El Niño-Southern Oscillation (ENSO) events, as well as decadal-scale shifts between warm and cold-phase states of the Pacific Decadal Oscillation (PDO, Mantua et al., 1997). Biological responses to past climate variability inform much of our understanding of the expected impacts from future climate change on biota in this region (Powell and Xu, 2011).

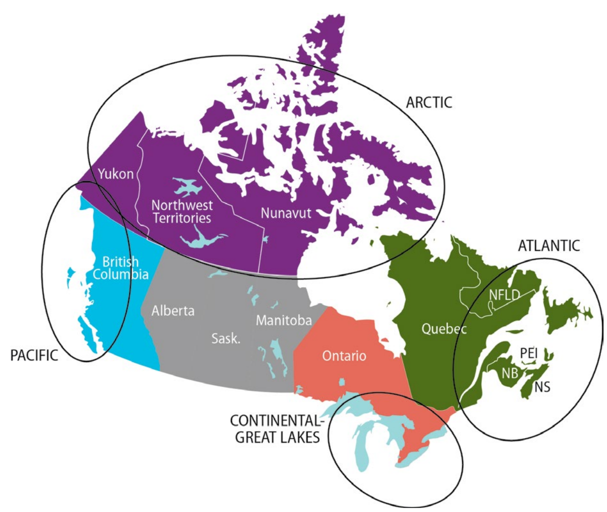

FIGURE 13: Map showing Canada's aquatic ecoregions.

3.2 CANADIAN AQUATIC FOOD SUPPLY

Access to the aquatic food supply is achieved through four main supply chains: commercial capture fisheries, culture fisheries, subsistence fisheries and recreational fisheries. Commercial capture fisheries deal with harvest of wild biota; culture fisheries refer to food produced in aquaculture facilities; subsistence fisheries deal mainly with Aboriginal fisheries, plus a component of the subsistence fisheries that overlaps with the broader Canadian recreational fisheries (e.g. food fishery in Newfoundland); and recreational fisheries refer to the licensed harvest of wild biota by individuals and recreational outfitters.

Commercial capture and culture fisheries products are among the most valuable food commodities produced by Canada. Together, harvesters, processors, distributors and retailers comprise Canada's "seafood" industry, which provides a vast array of fisheries products to local, regional, national and global markets (Figure 14). Approximately 85 percent of Canada's commercial fish harvest is distributed via exports to more than 130 countries (AAFC, 2012d). Commercial capture fisheries managed by Fisheries and Oceans Canada (DFO) remain a common property resource, though limited, rights-based mechanisms exist for many fisheries. Subsistence and recreational harvests fall under federal jurisdiction, which may be delegated in such a way that regulatory authorities vary greatly across the country. By contrast, culture fisheries are privately owned investments. Culture fisheries may be licensed and/or regulated by the DFO or provincial bodies on public or private lands. All post-harvest activities related to commercial capture and culture fisheries products are the responsibility of the Canadian Food Inspection Agency and Agriculture and Agri-Food Canada.

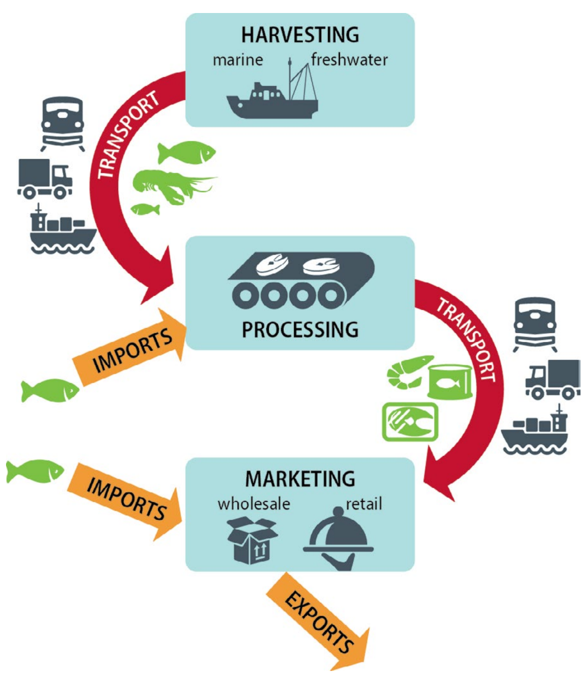

FIGURE 14: Diagram depicting the "fish-chain" – incorporating elements of the fisheries food system from ocean to plate.

Estimates of the quantity and value of commercial capture, culture, recreational and subsistence fisheries for each aquatic ecoregion are shown in Figure 15. Although harvest composition has varied considerably over time, the value of Canada's total unprocessed capture fishery harvest has remained relatively constant (DFO, 2011). However, species contributing to the yield and value of commercial capture fisheries vary greatly among regions (Table 2).

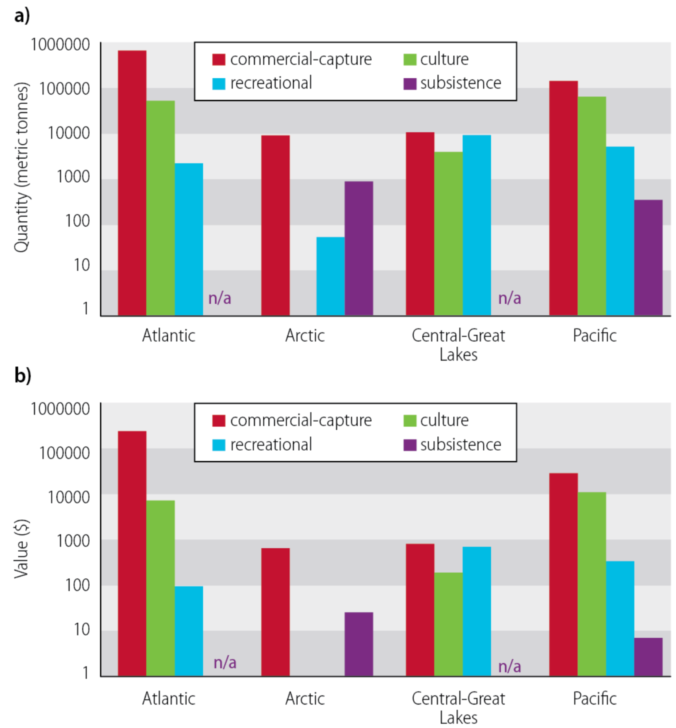

FIGURE 15: Estimates (log-scale) of the **a)** quantity and **b)** value of commercial capture, culture, recreational and subsistence fisheries for Canadian aquatic ecoregions (Atlantic, Arctic, Continental-Great-Lakes (CGL) and Pacific). Estimates are provided in log-scale because recreational and subsistence fisheries contributions relative to commercial capture and culture fisheries would not appear if plotted linearly *(Sources: Commercial capture fisheries data (metric tonnes; 2000-2010) retrieved from DFO Fisheries Statistics Branch. Recreational fisheries (number of fish) retrieved from DFO (2012c). Subsistence fisheries quantity (number of fish or metric tonnes) retrieved from DFO Pacific Food, Social and Ceremonial fisheries catch data, Zeller et al. (2011) and Robards and Reeves (2011). Quantity of marine mammal harvest is estimated by using the average weight of the ringed seal (~60kg). Numbers of fish was converted to weight using a conversion factor (Usher, 2000). Value was estimated for all fisheries by applying a mean protein replacement cost of $11.2/kg derived from two sources: Government of Nunavut and Nunavut Tuunggavik Incorporated, 2005 and G.S.Gislason & Associates Ltd and Outcrop Ltd., 2002).*

Ecoregion	Commercial capture fisheries[1]	Culture-fisheries[1]	Recreational fisheries[2]	Average (+/-SD) percent of population participating in recreational fisheries[3]	Subsistence fisheries[4]
Atlantic	Lobster, shrimp, crab	Atlantic salmon, mussels, oysters	Brook trout, Northern cod, mackerel	8 +/- 4.2	Atlantic cod, American lobster
Arctic	Greenland turbot, shrimp, Whitefish, Arctic char	n/a	Northern pike, Arctic grayling	10 +/- 8.9	Arctic char, lake whitefish, marine mammals
Continental-Great Lakes	Perch, yellow pickerel, lake whitefish	Rainbow trout	Yellow pickerel, perch	8 +/- 1.4	Lake whitefish, lake sturgeon
Pacific	Pacific halibut, Pacific salmon, crab, clams	Atlantic salmon, clams, oysters	Pacific salmon, trout	9	Pacific salmon

TABLE 2: Commercially or culturally important species harvested in ecoregions and percent of population participating in the recreational fishery by ecoregion *(Sources: [1]DFO Fisheries Statistics Branch; [2]DFO 2012c: [3]Statistics Canada 2009a. Atlantic is the average of NF, PEI, NB and NS, Arctic is the average of NWT, YK, NUN, CGL is ON, and Pacific is BC. [4]Atlantic: Lowitt (2011); Arctic: Zeller et al. (2011), Robards and Reeves (2011); CGL: Kerr (2010); Pacific: DFO Pacific Food, Social and Ceremonial fisheries catch data).*

Culture fisheries in Canada have only recently appeared as a major supplier of products to Canada's food system. Culture fisheries production has grown by over 130% since the mid 1990s (Statistics Canada 2009a) and was valued at nearly $846 million in 2011 (DFO, 2013b). In 2011, salmon (mainly Atlantic salmon) accounted for about 72% of total cultured-fish value, with shellfish and trout making up most of the balance (DFO, 2013b). While important contributors in the Pacific and Atlantic ecoregions, culture fisheries contributions from the Arctic are virtually non-existent and only minor in the CGL ecoregion.

The rise of culture fisheries is attributable to several factors including:

- lower annual variability in the ratio of costs to yield and increased certainty of year-round product availability to markets compared to wild capture fisheries;
- the capacity to respond to increased future demand from markets for high value products; and
- elevated control over operations, due to the private – rather than common – property nature of the resource (DFO, 2003).

Globally, cultured production of aquatic foods is forecast to continue to increase due to rising demand and improved production methods, and could potentially surpass global consumption of supply generated through commercial capture fisheries in the near future (Figure 16; OECD-FAO, 2011).

Subsistence fisheries, most often accessed by Canada's Aboriginal peoples, represent an economic system that is based on cultural and social networks that support the distribution of goods and food for consumption by the harvesters, their families and the community (Berkes, 1988). Subsistence fisheries are carried out in all four ecoregions. These fisheries contribute directly to food security by

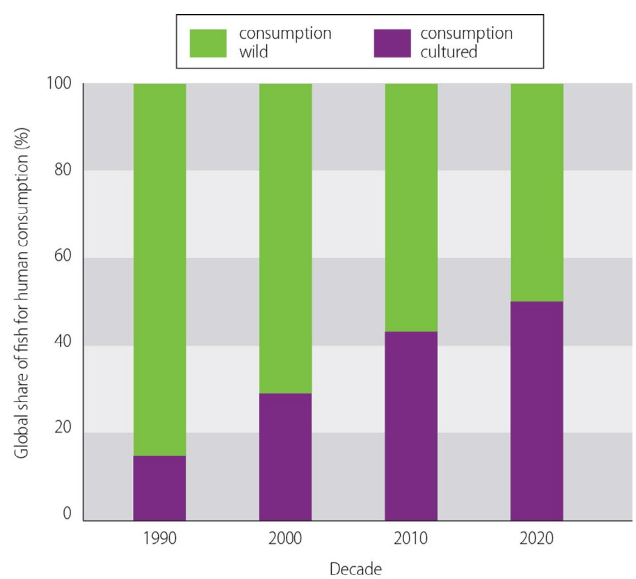

FIGURE 16: Global share of fish for human consumption originating from capture and aquaculture by decade *(modified from OECD-FAO Agricultural Outlook 2011 – © OECD 2011).*

supplying fish for consumption, or indirectly by generating earnings for the purchase of other food (i.e. the polar bear hunt) (*see* Box 3 and Chapter 7 – Human Health).

A recent estimate of marine mammal consumption put rates of harvest across the Canadian Arctic among the world's highest (>1000 animals per year), with more than 20 different species being utilized (Robards and Reeves, 2011). The value of the harvest, including several fish species and marine mammals for the Northwest Territories and Nunavut, was $3.4 million, based on a replacement cost of $20 per kg (G.S. Gislason & Associates Ltd and Outcrop Ltd., 2002). The Nunavut Fisheries Strategy (2005) estimated the replacement cost for Arctic char to be $2.3 per kg. We used the average of these estimates to represent the comparative value of subsistence and recreational harvests across ecoregions. Fisheries values presented here do not include any additional market or cultural valuations.

Recreational fishing is conducted for sport by many participants, from which a component of the harvest is kept for consumption. Estimated retained harvest for direct consumption by resident anglers was approximately 57 million fish (DFO, 2012c). These fisheries also generate economic gains for associated industries (lodges, guiding, equipment supply, etc.; Kerr et al., 2009) and are valuable from cultural and social perspectives. The popularity of recreational fishing varies across the country, with spending in Canada of $7-8 billion annually (OMNR, 2013b).

3.3 KEY FINDINGS FROM PAST ASSESSMENTS

'From Impacts to Adaptation: Canada in a Changing Climate 2007' (Lemmen et al., 2008) found that climate change would have significant impacts on the future integrity of freshwater and marine ecosystems across the country. Findings included:

- Species assemblages were expected to become more southern in character due to impacts of temperature change on the abundance and timing of key life history events.
- Increasing temperature would impact species at the edge of their distributional range, rendering them subject to extirpation or expansion.
- Significant changes in northern hydrologic systems, including reductions in permafrost, reduced sea ice duration and altered snow depth would affect fish and marine mammal distribution and abundance in the Arctic and Atlantic.
- Increased storm intensity and unpredictable weather would impact coastal erosion and sediment flux, thus altering nearshore foraging and spawning areas for aquatic animals.
- Shifting species distributions and abundance could encourage more distant-water and higher-risk activities by harvesters in some areas.

Responses of fish and impacts on fisheries were expected to vary due to differences in the geographic scale and physical boundaries that define freshwater and marine ecosystems. For example, while freshwater fish are relatively immobile in the short-term due to topographic fragmentation of aquatic systems at both small and large scales, Canada's marine fisheries have already exhibited many short-term changes in distribution and abundance of species in response to variations in ocean climate. In addition, evidence from Arctic ecosystems suggested that changes to the timing and success of life history events (e.g. migration, growth, reproduction etc.) for native species of fish and marine mammals – which have strong ties to regional food systems and food security – were already responding to climate-induced change.

Commercial capture fisheries are highly constrained by regulatory regimes in all parts of Canada, reducing the likelihood of rapid adaptation through harvesting of new species, or changes to fishing locations, times or methods of capture. In general, the adaptive capacity of the sector was dependent on governance keeping pace with changes to resources. Given projections of altered resource availability to various commercial capture fisheries, adaptation suggestions centred on developing strategies to identify either new capture fisheries opportunities, or alternately, to accelerate development of culture fishery opportunities that offer greater control over production outcomes. Changes to the design and management of fisheries were suggested as ways to increase the resilience of fisheries-dependent, social and economic systems to climate change.

3.4 CLIMATE CHANGE EFFECTS ON AQUATIC SYSTEMS AND FISHERIES

3.4.1. IMPACTS ON ECOSYSTEMS

A wealth of empirical observations, as well as modeling of climate-related impacts on freshwater (Chu et al., 2008; Minns, 2009; Sharma et al., 2007; 2009) and marine ecosystems (Beaugrand et al., 2002; 2008; Brander, 2007; Cheung et al., 2009; 2010; Blanchard et al., 2012) suggest that changes to biodiversity and biota supporting fisheries at regional scales can be significant. However, evidence of climate change impacts on aquatic ecosystems is variable and region-dependent (Burrows et al., 2011).

Climate and socioeconomic change in Canada's Arctic ecoregion appear to be interacting at historically unprecedented rates (Carmack et al., 2012; Wang and

Overland, 2012). The loss of Arctic sea ice will have profound effects on habitat states, species distributions and range expansions (e.g. invasive or colonizing species) associated with ecosystem structure and productivity changes (Behrenfeld et al., 2006; Grebmeier et al., 2006; Meltofte, 2013).

In the CGL ecoregion, decadal-scale observations of shorter winters, warmer river and lake temperatures, intensified rain and snow events, and decreased ice cover on lakes (Environment Canada/US EPA, 2009) all reflect changing climate. Climate change appears disadvantageous to CGL cold-water species, but advantageous to expansions of warm-water species at the northern end of their range and to existing or new waves of invasions by alien species. Thus, the history of highly unstable species composition in the CGL is likely to persist or even accelerate under the influence of climate change; affecting ecosystems, fish, fisheries and economies (DFO 2012a, b; 2013c, d; Meltofte, 2013). Although some climate-induced changes in the Arctic and CGL ecoregions are creating prospects for new commercial capture fisheries (MacNeil et al., 2010), they also threaten the security of food supplies from subsistence fisheries maintained for millennia by Aboriginal peoples (Meltofte, 2013).

By contrast, in the Pacific and Atlantic ecoregions, changes in marine ecosystem states and fisheries yields associated with variations in ocean climate have been large enough that clear evidence of long-term climate change impacts, as opposed to climate variation impacts, has yet to emerge (DFO 2012a; DFO 2013d). Subsequently, in Canada's Atlantic and Pacific ecoregions, responses of fish and fisheries to climate change are generally projected from conceptual or simulation models of consequences of persistent state changes, informed by responses to historic variations of climate conditions observed during shorter intervals (Overland et al., 2010).

3.4.2 IMPACTS ON AQUATIC BIOTA

Impacts on regional ecosystems, fisheries and associated food systems originate from general processes that include: (1) changes in ecosystem production via 'top-down' (harvest by humans) or 'bottom-up' (predator- and nutrient-driven) impacts that cascade through food webs (Pace et al., 1999; Ware and Thomson, 2005; Frank et al., 2006; Hoekman 2010); (2) life history event disruptions that induce changes in productivity or distribution for key taxa that support fisheries directly (Chavez et al., 2003; Martins et al., 2011); and (3) permanent changes in species presence or absence (Perry et al., 2005) that relate to range shifts (i.e. expansion/contraction) of native and alien invasive species (Hellmann et al., 2008; Minns, 2009).

CASCADING EFFECTS OF ECOSYSTEM PRODUCTION CHANGES

Fisheries supply from a given ecosystem is regulated naturally by aquatic climate and species interactions within complex food webs. Changes in these interactions can affect fisheries production (Ware and Thomson, 2005; Grebmeier et al., 2006; Mandrak and Cudmore, 2010; Shackell et al. 2012) and provide a basis for predictions of future production changes.

Aquatic ecosystems at high latitudes appear more strongly influenced by climate variation and change than by any other driver (Meltofte, 2013). Freshwater input and heat content of Arctic marine water masses have increased since the 1970s and are related to a two-fold increase in the temperature of their Atlantic-origin water (Proshutinsky et al., 2009), reductions in sea surface salinity (Polyakov et al., 2008) and alterations to the amount and duration of summer sea ice (Deser et al., 2000; Niemi et al., 2010; *see also* Chapter 2). These physical changes support a longer growing season and an observed trend for increased plankton productivity in Arctic waters (Niemi et al., 2010; Meltofte, 2013). In the western Arctic, a change from arctic to subarctic conditions has already resulted in a northward shift of the more productive, pelagic-dominated marine ecosystem, previously limited to the south-eastern Bering Sea, and the displacement of marine mammal and benthic fish populations (Grebmeier et al., 2006).

DISRUPTED LIFE HISTORY EVENTS

Climate change may broadly induce biophysical impacts at the base of aquatic ecosystems or act, more narrowly, to directly influence key life history stages or events of particular species that support fisheries in Canada's ecoregions (*see* Case Study 4). Modelling studies generally suggest that in a warmer climate, the geographic centres of production and/or harvest of commercially important fish species would shift northward or inshore, thus providing potentially greater access to several species (e.g. tuna, mackerel) in Canadian waters (Ainsworth et al., 2011).

RANGE SHIFTS AND INVASIONS

Aquatic species in the Arctic are already undergoing range shifts associated with circulation changes in Pacific and Atlantic Ocean water masses (DFO, 2012a). In southern freshwater systems, models examining range expansions of important harvested species suggest variable outcomes that depend on species' thermal preference (Table 3). Climate-induced production losses of cold-water species (walleye and lake trout) that currently support key commercial and recreational fisheries, together with invasions or increased production of less valuable warm-water species (carp, catfish), are likely to drive many future changes in CGL fisheries and associated management systems (e.g. lamprey control).

CASE STUDY 4

PACIFIC SALMON AND CLIMATE CHANGE

In the Pacific ecoregion, decadal-scale changes in the accessible supply of Pacific salmon driven by climate regime shifts (Mantua et al., 1997; Beamish et al., 1999; Figure 17), treaty negotiations with First Nations (Brown, 2005), and the emergence of aquaculture as a major source of supply (Robson, 2006) have profoundly altered the structure and economic security of commercial capture fisheries in general and the salmon fishery in particular (Meggs, 1991; Glavin, 1996; Brown, 2005). Dramatic declines in the supply available to fisheries subsequent to the 1990s, especially those focused on key salmon species, have been accompanied by elevated cross-cultural tensions (Harris, 2001), and local community instability along with coast-wide reorganization of fishing fleet and fish processing infrastructure (Glavin, 1996; Brown, 2005).

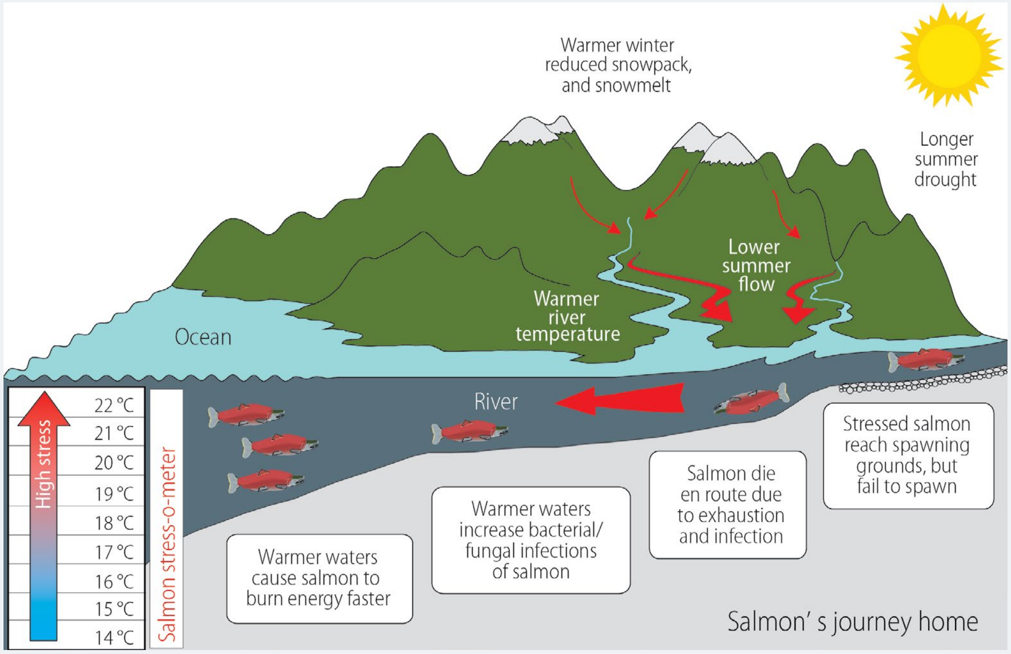

FIGURE 17: Climate change effects on waterbodies impact adult Pacific salmon along the journey to their natal streams *(Source: NRCan, 2009)*.

Given the regional, cultural and economic importance of Pacific salmon, these species have been the subject of ongoing research on linkages between climate change and changes in production and/or fisheries yield (e.g. Beamish and Bouillon, 1993; Mantua et al., 1997; Finney et al., 2002; Irvine and Fukuwaka, 2011; Rogers and Schindler, 2011). Sockeye salmon in particular have been the subject of several major reviews, motivated in part by a formal Public Inquiry (Cohen Commission 2010-2012), following record low (2009) and record high (2010) variations in returns and catch of Fraser River fish. Technical reports from the Cohen Inquiry (Hinch and Martins, 2011; McKinnell et al., 2011) allow a reasonably firm conclusion that recent climate change trends in freshwater habitats of the Fraser River were leading to reduced production through influences on adult migration-and-spawning success (e.g. Cooke et al., 2004; Crossin et al., 2008) as well as on juvenile production in freshwater (Peterman and Dorner, 2011). By contrast, although there is strong evidence of a broad regional decline in production of sockeye salmon populations from central to south coastal British Columbia (Hyatt et al., 2008) associated with changes in marine systems (Peterman and Dorner, 2012), the trend is not clearly attributable to long-term climate change as opposed to shorter-term variations that are within the range of historic observations for this area.

These results are consistent with McDaniels et al. (2010) regarding the heightened vulnerability of salmon migration, spawning and incubation success, to climate change effects already apparent in freshwater. Adding to this, longer term climate change impacts in both freshwater and marine environments will accumulate across all life history stages of salmon to produce negative outcomes for southern populations exposed to increasingly unfavourable environments, and either neutral or positive outcomes for northern populations (Healey, 2011).

Information on invasive alien species (IAS) and climate change in aquatic systems in Canada is limited (*reviewed by* Smith et al., 2012). However, in general, responses to climate variation and change will differ between freshwater and marine systems because of differences in constraints on species dispersal (Reist et al., 2006), combined with impacts of invaders on native species already under stress (Pimentel et al., 2005). Overall, climate change will likely exacerbate the impacts of aquatic invasive species on fisheries (Rahel and Olden, 2008), especially in the Great Lakes (USGS, 2012) and Arctic ecoregions (Cheung et al., 2009; Meltofte, 2013).

3.5 CLIMATE CHANGE IMPACTS ON AQUATIC FOOD SYSTEMS

3.5.1 IMPACTS ON CAPTURE FISHERIES (COMMERCIAL AND RECREATIONAL)

Our understanding of the effects of climate variation and climate change on fish and fisheries is frequently restricted to modelled predictions for both freshwater (*see* Table 3) and marine ecosystems that do not reflect cumulative climate effects and interactions on fisheries yield (with some exceptions, e.g. *see* Crain et al., 2008; Halpern et al., 2008; Ainsworth et al., 2011). However, it is still evident from the models that changes to biodiversity at the regional scale are likely to be significant (Cheung et al., 2009; 2010; Polovina et al., 2011; Meltofte, 2013; *see also* Chapter 6 – Biodiversity and Protected Areas). While effects on biodiversity do not necessarily result in lower biomass or fewer species in aggregate regional catches, the current composition and species-specific yield from regional assemblages are expected to undergo rapid change (Overland et al., 2010; Burrows et al., 2011) resulting in spatial redistribution of global catch potential from southern to more northern waters, that will eventually alter major fisheries in Canada's Atlantic and Pacific regions (Cheung et al., 2009; 2010; Polovina et al., 2011).

In the CGL ecoregion, cumulative impacts of alien invasive species (Mandrak and Cudmore, 2010), climate change, regional human population growth and potential management responses are likely to exacerbate the centennial-scale record of boom-and-bust production observed for both commercial and recreational fisheries (Pimentel et al., 2005; Environment Canada and USEPA, 2009; OMNR, 2013a). Although major commercial and recreational fisheries have never existed in Canada's Arctic, expansion of entirely new suites of subarctic species in response to warming is underway (e.g. salmon; Nielsen et al., *in press*). Thus, major changes to Arctic marine ecosystems, fish and fisheries appear inevitable, and it is also likely that gross production from whatever species assemblage eventually does emerge will support increases in marine fisheries yields (Reist et al., 2006). These resources will contribute to northern food supply and will likely expand in importance under precautionary management (Stram and Evans, 2010; Meltofte, 2013), as needed infrastructure (i.e. small craft harbours) is put in place.

Species type	Scenario outcome	Reference
Cold-water species: lake trout	Possible 30-40% drop in suitable habitat available for lake trout in Ontario by the end of the century	Minns, 2009
Cold-water species: cisco	Warming may extirpate between 25%–75% of cisco populations	Sharma et al., 2011
Cool-water species: walleye	Warming may increase available habitat, suggesting a northward shift in the location of the walleye fishery	Hunt and Moore, 2006
Cold-water species assemblage	Cold-water species distributions may be reduced to less than 67% of sites within 43 studied watersheds by 2025 (worst case) with the strongest impacts on the most southerly watersheds	Chu et al., 2008
	Warming was a bigger risk factor than an invasive predator (rainbow smelt) for extirpation from cold water lake habitats	Sharma et al., 2011
Warm-water species: smallmouth bass	Suitable habitat for smallmouth bass may expand to include most lakes in Canada by 2011	Sharma et al., 2007
Species invasion interactions	A northward gain in suitable habitat by smallmouth bass could increase the number of lakes with vulnerable trout populations to 1612 lakes (20% increase) by 2050	Sharma et al., 2009

TABLE 3: Outcomes for freshwater fish species examined under various climate change scenarios (*see also* Dove-Thomson et al., 2011).

Warming of the Arctic will also impact freshwater habitats (Minns, 2009; Sharma et al., 2009) through changes to river and lake ice conditions (Prowse and Brown, 2010), with potential production losses of iconic salmonid species because of their dependency on natural winter ice regimes (e.g. Linnansaari and Cunjak, 2010). Endemic, historically-isolated Arctic species (e.g. char, whales, walrus and polar bear) and fisheries are vulnerable to population decline given expected combinations of climate change, other anthropogenic impacts, and aquatic species invasions (Meltofte, 2013).

Recent assessments (DFO, 2012a, b; 2013c, d) suggest that drastic changes in fisheries yield and value are unlikely to occur in any of Canada's ecoregions within the next ten years. The observations above suggest that, in the longer-term, aggregate fisheries yield in Canada will increase but complex ecosystem and species reorganization outcomes will dictate overall economic value, which remains highly uncertain. Finally, any or all of the changes noted above to commercial capture fisheries yield and related supply chains may influence subsequent distribution patterns among nations (Allison et al., 2009). Changes such as these at either domestic or global scales may translate into shifts in price and value of Canadian harvests, with impacts to gross and net incomes from fishing and fish processing. Changes to operational costs associated with several links in the fisheries food chain could necessitate expansions or contractions of fleet size for countries such as Canada (Sumaila et al., 2011). However, in high latitude areas where harvests do not currently exist, there is potential for financial gain for early participants in new fisheries (Arnason, 2007).

3.5.2 IMPACTS ON CULTURE FISHERIES

Climate change has the potential to affect the integrity of aquaculture infrastructure (e.g. net pens, hatcheries), physical habitat settings and species produced. For example, production locations and practices will have different susceptibilities to sea level rise and increases in the severity or frequency of storm events (Moore et al., 2008). In general, from both production and infrastructure perspectives, threats to marine finfish aquaculture appear to be less than for shellfish. Unlike shellfish, cultured finfish do not rely on food sources produced in the culture environment and they do not accumulate biotoxins or coliforms. However, the performance of both finfish and shellfish may be affected by changes in ocean temperature, dissolved oxygen, salinity, acidity (*see* Chapter 2 – An Overview of Canada's Changing Climate) and the occurrence of harmful algal blooms, which may result in lost productivity or direct mortality (Moore et al., 2008). While cultured finfish production is currently dependent on supplies of wild caught forage fish used to produce fish meal, model-based analyses suggest that climate-induced losses of current fish meal sources may be dealt with through innovative development of fish meal substitutes (Merino et al., 2010). Governance and demand-driven costs of alternate sources of fish meal will play strong roles in future production of cultured finfish (Merino et al., 2012). Overall, despite many potential risks, the aquaculture industry should be able to adapt to changing conditions either through technological advances or relocation.

3.5.3 IMPACTS ON SUBSISTENCE FISHERIES

Traditional foods provided by the natural environment remain central to Aboriginal health (Hansen et al., 2008, Wheeler et al., 2010). Climate change is likely to induce rapid changes in animal migration patterns, ranges and productivities, which may affect access to a reliable food supply (*see* Box 3; and Chapter 7 – Human Health). These impacts will exacerbate food insecurity for traditional subsistence fisheries in some regions. This will be especially apparent where there are other factors limiting subsistence fisheries, such as fishing allocation policies in the Pacific (Harris, 2001) and where climate variability and change have already resulted in impacts (e.g. in the Arctic; Lemmen et al., 2008).

BOX 3

NON-COMMERCIAL FOOD SUPPLY

Higher temperatures and changing precipitation patterns are already having an impact on rural and remote environments and communities (Lemmen et al., 2008; A Northern Vision, 2011). Key life-history events for cold-adapted marine mammals at the top of arctic food chains, which are important to regional supply chains, now appear increasingly vulnerable to climate change impacts and potential increases in human activity in the North (Niemi et al., 2010; Meltofte, 2013). Observed impacts of relevance to food systems and security identified by Lemmen et al. (2008) and A Northern Vision (2011) include:

- Winter ice roads have shorter seasons and cost more to maintain, necessitating alternate, more expensive food transport options.
- Permafrost is degrading, affecting the integrity of food delivery infrastructure.
- Arctic sea ice is thinning and threatening ocean mammals and hunting while potentially increasing shipping, tourism, resource exploration and industrial activities.
- Wildlife migration patterns are changing and altering availability of traditional foods (*see* Chapter 6 – Biodiversity and Protected Areas).
- Weather variability and extremes are increasing and changing hunting and transportation routes and increasing the dangers associated with being out on the land or water.
- Traditional food supplies are harder to find as species move or disappear from the region.
- Forests are becoming increasingly vulnerable to pests and forest fires, which is affecting the ecosystems of traditional food supplies (*see* Chapter 3 – Natural Resources).
- Shoreline erosion and storm surges are damaging infrastructure and supply routes.
- Increasing port access, through loss of sea ice, could disrupt traditional lifestyles, bringing new pests, diseases and less healthy foods.
- Melting glaciers are causing short term flooding and may lead to long term drought after they are gone.

The continued effects of climate change on northern and remote communities within Canada could make these communities more vulnerable to food security issues. The homelands, culture, traditional knowledge, and hunting habitats of northern Indigenous peoples could be directly affected. Furthermore, many of these communities depend upon country foods such as wild meat, fish, birds, berries and other plants, all of which are sensitive to changes in climate. Barren-ground caribou in Northern Canada, for example, travel great distances from wintering grounds to calving grounds to insect-relief areas and back again each year. The caribou are now encountering deeper and heavier snow than in the past and appear to be moving away from traditional hunting grounds. Changing climate may also result in reduction or loss of wetlands such as sloughs and marshes, which are important nesting and feeding areas for many migratory birds, and could cause decreasing numbers of birds (Meakin and Kurvits, 2009; *see also* Chapter 6 – Biodiversity and Protected Areas).

Impacts on the Arctic marine food chain will be location-specific. If warmer temperatures affect one part of the chain, they may have ramifications on the entire marine ecosystem. For example, as sea ice melts earlier in the spring and the edge of the icepack gets farther away from land, polar bears have a harder time reaching the seals they require for survival and hunters will require more resources to reach more distant hunting grounds (Ford, 2009).

While northern soils and climate conditions are largely unsuitable for agricultural production, there are some areas that currently have moderate agricultural capability. A longer growing season could allow cultivation of a broader diversity of crops and higher yields, although future precipitation patterns could limit this potential (Ogden and Johnson, 2002). Furthermore, a longer growing season could cause a shift northward in edible plant foods, animals that graze those foods and their predators. While this could increase access to country foods, shifting biomes can also bring or strengthen new diseases and pests that affect humans, flora and fauna (A Northern Vision, 2011).

Climate change planning is an important exercise, and benefits from larger-scale planning activities, such as *The Pan-Territorial Adaptation Strategy: Moving Forward on Climate Change Adaptation in Canada's North* (A Northern Vision, 2011), which proposes approaches for collaborative actions in the three territories, while supporting territory-specific initiatives to meet unique challenges. For example, there is a desire to replace high sugar, high fat, nutrient poor "store-bought" foods that are implicated in rising rates of obesity and diabetes, with healthier traditional and country foods (Kuhnlein and Receveur, 2007) and to consider alternative sources, such as greenhouses and agriculture to supplement the food supply (A Northern Vision, 2011).

3.6 ADAPTATION

3.6.1 VULNERABILITY AND ADAPTABILITY OF FISHING COMMUNITIES

Continued climate change is expected to induce changes to aquatic ecosystem structure and productivity with resultant changes to the quantity, quality and species composition of fish currently entering food supply chains from Canada's four major fisheries ecoregions. Depending on the resilience of regional supply chains, varying adaptations will be required to minimize vulnerability and maximize opportunity. When ranked at a global scale relative to developing nations with a high dependence on fish in local diets, Canada exhibited low vulnerability to impacts of climate change on its aggregated fisheries supply chain (Allison et al., 2009). However, aggregate statistics often conceal finer-scale differences in food system vulnerability or levels of resilience associated with the full range of culturally and economically important fisheries. In a supply chain with low adaptive capacity, socio-cultural consequences, especially in terms of the food security of the most vulnerable, may result from even small disturbances (Thompson and Scoones, 2009). By contrast, disturbance to more resilient supply chains may bring opportunities, innovation and new pathways of development (Thompson and Scoones, 2009). Consideration of historic responses of fisheries and fishing communities to variations in supply may be used to clarify the origins and nature of vulnerability or resilience exhibited by subsistence, wild-capture and culture fisheries.

3.6.2 SUBSISTENCE FISHERIES

Subsistence fisheries, and especially those of Aboriginal peoples in remote communities in Canada's Arctic and Pacific ecoregions, play a defining role for local culture. Subsistence fisheries have repeatedly emerged as a central issue in more than a century of cross-cultural conflict over fisheries in British Columbia (*see* Harris 2001, 2008). Similarly, entitlements to harvest traditional species to meet food, societal and cultural needs of Aboriginal groups scattered from the Yukon to the eastern Arctic are key elements of modern-day treaties with the Government of Canada (*see* Harris and Millerd, 2010, for review). As a result, the maintenance of security of supply of traditional species harvests is extremely important to Aboriginal peoples in Canada. As climate-induced changes to freshwater and marine ecosystems are likely to alter yields and species composition outside of their historic range (*see* Section 3.4), traditional subsistence fisheries harvested at fixed locations or times would appear to be highly vulnerable, with relatively little adaptive scope to maintain customary harvest in cases where the subject species are severely reduced or eliminated by future climate change. This is particularly true in the case of inland and anadromous species.

3.6.3 COMMERCIAL CAPTURE FISHERIES

Commercial capture fisheries and the communities that rely on them in the Atlantic, Pacific and CGL ecoregions of Canada have all recently experienced decadal-scale changes in the distribution, abundance and harvest of historically dominant species supporting fisheries. Although these changes cannot be ascribed solely to climate change, they provide useful observations of the relative vulnerability and adaptive capacity of fisheries-dependent communities under stress. For communities with a high degree of economic dependence on fisheries, the magnitude of these changes has been most dramatic in the Atlantic (*see* Case Study 5), but is still significant in the Pacific and CGL ecoregions. Costs and benefits of these changes have been unevenly distributed and economic recovery of communities appears to depend highly on their initial economic well-being (Murray et al., 2005).

Variable climate regimes combined with ongoing waves of exotic species invasions have also had dramatic effects on commercial capture and recreational fisheries in Canada's CGL ecoregion. Although these changes have been accompanied by considerable economic losses (Pimentel et al., 2005), both types of CGL fisheries appear to have at least partially adapted to reductions in harvest of native species (e.g. lake trout, whitefish) through increased harvest of exotic species (e.g. rainbow smelt, Pacific salmon). Moreover, the relatively weaker dependence on fisheries for food-system security in the majority of local communities of the CGL region suggests they have lower vulnerability to climate impacts on fisheries supply chains.

3.6.4 CULTURE FISHERIES

The relative absence of control over the basis for wild production that sustains 'wild' fisheries versus increased levels of control associated with intensive culture fisheries is likely to become increasingly important in the face of future climate change. The use of climate change projections to adjust production timing, location of operations and/or identity of cultured species confers an advantage to culture fisheries that is not readily achievable for other supply chains (Barange and Perry, 2009). Thus, although culture fisheries are not without issues (e.g. *see* PFRCC, 2003; Robson, 2006), they clearly display lower levels of vulnerability and greater scope for adaptation to changes in environmental conditions, including future climate change, than either subsistence or commercial capture fisheries. However, the resilience of all types of fisheries will also require that appropriate institutional mechanisms are in place to respond to impacts of future climate change.

3.6.5 INSTITUTIONAL ADAPTATION

Technological, behavioural and cultural changes at multiple scales along the fisheries food supply chain are adaptive responses to climate variation and change impacts (*see* Case Study 5). However, all such changes interact, and are interdependent with regulatory and policy frameworks of Fisheries and Oceans Canada (DFO) or their delegates (i.e. provincial agencies, resource management boards). There are several broad categories of activities which together may be viewed as comprising a type of "soft", institutional infrastructure that climate change will influence, and from which general adaptation responses will emerge (Table 4).

The fisheries section of this chapter has principally focused on climate-induced variations in food production and the consequences for harvest as the foundation underlying all subsequent elements of the fisheries food system (e.g. processing, distribution, exchange and marketing, consumption). Although this focus has precluded assessment of climate impact and adaptation responses along the full length of aquatic food supply chains, it is important to recognize their importance. Consequently, a case history of interactions among changes in natural systems and human systems associated with the production and utilization of northern cod is presented to illustrate important and documented interactions among multiple components of a regional food supply chain (*see* Case Study 5).

3.7 SUMMARY

Response of fish, as measured by historic trends in climate variation impacts on commercial capture fisheries, suggests that, in aggregate, Canada's fisheries food systems exhibit moderate vulnerability and high adaptive capacity to climate change. In the future, these fisheries will likely continue to harvest a diversity of species that supply food chains at local and global scales. However, this conceals the wide range of vulnerabilities exhibited by traditional, rural subsistence fisheries (high vulnerability), smaller-scale commercial capture and recreational fisheries (moderate vulnerability) and culture fisheries (lower vulnerability) to risks posed by climate change.

Institutional Infrastructure Element	General Adaptation Response
Licensing	Vary licensed time, place and harvest quantity to maintain sustainable fisheries
Fisheries Management	Vary investment in monitoring and evaluation of stock status and environmental conditions to ensure effective management of existing fisheries
Fisheries Research and Habitat Management	Vary investment in new science supporting existing or new capture and culture fisheries management systems
Conservation of Species at Risk	Regulate fisheries and habitat management systems to control risk of extirpation of endangered species
Negotiation and Maintenance of Treaties	Modify new or existing treaty provisions to accommodate climate change impacts as climate change risks warrant

TABLE 4: Key institutional adaptation responses by institutional infrastructure element.

CASE STUDY 5

ENVIRONMENTAL AND ECOSYSTEM CHANGES AND IMPLICATIONS ON NORTHERN GULF SEAFOOD SUPPLY CHAINS AND DIETARY PATTERNS IN NEWFOUNDLAND AND LABRADOR

For nearly three centuries, the cod fishery was the foundation of coastal communities in Newfoundland and Labrador (NL). From the beginning, cod (Figure 18) was a dietary staple and an important export product for the economies of Eastern Canada. Traditional NL foodways changed rapidly with the influx of modern goods and services following confederation with Canada in the late 1940s, and the extended exclusive economic zone jurisdiction over marine resources in the 1970s. Seafood production transformed from traditional small-scale domestic production in the 1950s to industrial production by the 1980s (Sinclair, 1985; Wright, 2001). By the early 1990s, several cod stocks in NL were placed under moratoria because of severe resource decline due to both overfishing and environmental changes (Hutchings and Myers, 1994; Rice et al., 2003). The Northern Gulf cod fishery is a case study for exploring the potential ramifications of environmental and ecosystem changes for seafood production, food security and dietary patterns. The Northern Gulf cod fish stock is migratory in the Gulf of St. Lawrence bordering NL and Quebec.

Both 'potential' and 'realized' fisheries are the product of a three-stage chain: 1) marine ecosystems; 2) harvest activities; and 3) post-harvest activities (processing, marketing and consumption). Potential opportunities along the fish chain can be used to improve institutional linkages for biodiversity conservation, resource sustainability and community well-being, and, in the face of further climate change, the necessary adaptive capacity to deal with these impacts.

FIGURE 18: Fisherman filleting cod.

Marine ecosystems

As typical of large ocean fish stocks, Northern Gulf cod undergo extensive spawning and feeding migrations associated with critical habitats, temperature changes, and food availability (Yvelin et al., 2005). The geography and biophysical complexities of the region, characterized by arctic fjord systems, mean that small environmental changes due to temperature, runoff, water mass, or ocean currents affect the cold intermediate layer and sea surface temperature with ramifications for zooplankton production, larval dispersal, and stock biomass (Frechet, 1990; Quinjon and Snelgrove, 2005; Gailbraith, 2006; Galbraith et al., 2012). Colder temperatures and changes in oceanographic conditions were reported to affect the reproductive rate of cod fish populations leading up to population decline in the mid-1980s (DFO, 2010). Similar temperature impacts were noted for the decline in the years 2003 and 2008 in Northern Gulf fisheries (DFO, 2010). Changes in oceanic circulation between the 1930s and 1980s resulted in a worsening of the hypoxic conditions found in the deep channels (Gilbert et al. 2005), to the point that the deeper estuarine waters became virtually unusable by cod (Plante et al., 1998), which appears to have decreased productivity of the northern Gulf stock (Chabot, 2004). There were also high cod mortality rates due to predation from seals and high exploitation by fisheries (DFO, 2010). These changes in the pre-harvest stage affect ecosystem structure and function, predator-prey relationships, and have ramifications for allocation and catch quotas of recreational food and commercial cod fisheries.

Harvest activities

In addition to climate variability, the stock collapse has been attributed to many factors including ineffective management strategies, illegal and unreported fishing that affects stock assessment and foreign overfishing (Bavington, 2010). The spawning stock biomass fluctuated from historical highs of 378 000 tonnes in the mid-1980s with a gradual decline to 9000 tonnes in 1993, prompting a complete moratorium on commercial fishing from 1994 to 1996 and in 2003 (DFO, 2010). Consequently, all foreign and most domestic fishing fleet activities were suspended, and total catch in 2010 was just 2% of historical levels.

The collapse of cod fisheries also led to new rules surrounding local seafood access and allocation, as demonstrated by the 1997 Professionalization Act. Limits on subsistence fishing for cod were imposed that affected community access and choice of dietary protein. These policy changes raised concerns about food security and the viability of fishing-dependent communities (Lowitt, 2011).

Twenty years after the moratorium, the cod stock has not rebuilt (Khan, 2011). There are small quotas for commercial and food fisheries. Some households access cod and other seafood through recreational fisheries. For the region as a whole, about 161 tonnes of cod were caught in 2006 for the recreational food fisheries, compared to 1742 tonnes for the commercial capture fisheries (DFO, 2007; 2010). While

Case Study 5 continued on next page

wild fisheries declined and remain in collapse, aquaculture has grown 150% since the moratorium (DFO, 2011). At the same time, there has been a shift in ecosystem structure and changes in target species from ground fish to even more lucrative shellfisheries (Savenkoff et al., 2007). Overall, shellfisheries accounted for 60% of the total landings and 84% of the landed value of all capture fisheries in NL in 2010 (DFA, 2011). Recently however, warmer waters have been reported to affect moulting in shellfish such as crab (DFO, 2008; Vasseur and Catto, 2008). Such impacts of climate variability on crab resources have resulted in management measures that restrict fishing to certain geographical grids in order to protect 'soft shells'. These management measures have consequences on harvesting strategies and revenues from shellfish fishing operations, especially if these conditions persist (Schrank, 2005; DFO, 2008).

Post-harvest activities (processing, marketing and consumption)

Processing and distribution networks have also transformed in reaction to the collapse, to meet certification and consumer needs. The marketing and distribution channels for seafood have changed from a predominantly US market in the pre-collapse period to new global markets in the post-collapse period. These changes along the fisheries food-supply chain, at various spatial scales, have brought substantial social and economic transformation to coastal regions in terms of community survival and livelihood opportunities as well as access to local seafood (Ommer et. al., 2007).

The cascading effect resulting from changes in marine ecosystems that affect livelihoods and food security are very evident along the fisheries food-supply chain from 'ocean to plate'. Findings from two recent surveys indicate that seafood consumption is declining in Newfoundland (Solberg et al., 2007; Lowitt, 2011). Surveys show that consumption of shrimp has increased, and this may be one way local households have adapted their diets following the shift in ecosystem structure. However, indicative of its important place in traditional dietary patterns, cod remains by far the most frequently eaten type of seafood. In the 2011 survey, 81% of households said they eat cod "often", compared to 31% for shrimp, 27% for lobster, and 17% for crab (Lowitt, 2011).

A decline in seafood consumption may be influenced by lower commercial quotas and decreasing subsistence and recreational fishing activities, combined with tighter regulations around local seafood access, resulting in potentially less fish being landed and available for local consumption. The participation rate in the recreational food fishery is also among the lowest in a provincial survey (DFO, 2007), reflecting environmental changes and impacts on cod fish stocks. At the same time, fishing seasons are becoming shorter for many species, with the consequence that local seafood is available for purchase for fewer months of the year.

Institutional response and adaptation mechanisms

Changes that have taken place in ecosystems, target fisheries, and institutional responses have implications for the food security of coastal communities that have historically depended on seafood as an important part of their diet. Food systems are increasingly integrating other policy areas – including health and environment – to help improve capacity to adapt to environmental and resource challenges (MacRae, 2011).

The adaptive capacity of communities to respond to environmental and ecosystem changes, including changes in food systems, can be strengthened through multi-level governance arrangements that emphasize community empowerment and shared responsibility. By understanding the interactions of social and economic drivers with climate variability and ecosystem changes, effective institutions and adaptive governing capacity can be enhanced to better deal with climate variability and change.

4. CONCLUSIONS AND MOVING FORWARD

Food production covers a broad spectrum of activities involving agriculture, fisheries and non-commercial food supply. While further research will continue to enhance adaptation decision-making, adaptation is moving forward with the goal of building resilience against the variability of both short-term weather and long-term climate. The ability of the food sector to grow in market value will depend on its ability to adapt to the new conditions brought about by changing climate and changing geopolitical conditions. The complex, rapidly changing environment requires a flexible and adaptable food sector. Adaptability amongst the sectors discussed in this chapter is evident, with examples of past adaptation (e.g. to drought on the Prairies, cod decline in Atlantic Canada), current initiatives (e.g. shifting types of crops, fishing new species) and planning for the future (e.g. insuring losses from bluetongue outbreaks, the Pan-Territorial Adaptation Strategy).

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