Chapter 26. North America

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Note to Reviewers

North America ranges from the tropics to frozen tundra and contains a diversity of topography, ecosystems, economies and cultures. While across the continent, adaptive capacity is relatively high, there is diversity in levels of human development, particularly between Canada and the United States on the one hand, with human development indices (HDI) of 0.902 (fourth place) and 0.888 (eighth place) respectively, and Mexico, with and HDI of 0.750 (fifty sixth place, UNDP 2010, http://hdr.undp.org/en/reports/global/hdr2010/). Furthermore, within each country, a wide variety of conditions exist, not only in levels of human development and social mobility, but also in governance systems and other factors that are important determinants of adaptive capacity.

The vulnerability of North American societies and ecosystems to climate change varies considerably depending on geography, scale, social or ecological systems, demographic sectors and institutional settings. This chapter attempts to account for some of the diversity of vulnerability. It does so by analyzing a number of economic sectors, regions, demographic groups and “natural systems” that will be affected by climate change in different ways. The chapter also examines issues that cut across countries, sectors, communities, and systems.

What is not attempted here is a comprehensive summary of how all sectors and regions of North America will be affected by climate change. This is not done for three reasons. First, this chapter builds on the findings of prior IPCC reports aimed at being more comprehensive. Second, there is insufficient space in a single chapter to comprehensively and adequately summarize the myriad of climate impacts, sensitivities and capacities to adapt across North America. Third, each country has produced detailed national reports on climate change impacts and vulnerabilities (Lemmen et al., 2008, USGCRP, and Mexico’s latest national communication). This chapter has a two-fold goal, not attempted in the vast literature on climate change impacts in each country: to compare and contrast the different weight of “natural” and “human” factors in explaining current and potential climate change impacts of climate change in key issues of concern (e.g., water, health, urban development); and to explore how governance, irreversibility and other key themes cut across North America. It is the hope of the writing team that such an analysis will communicate [some] the complexity and texture of the many ways that North America is already being affected by a changing climate and could be affected by projected changes in climate over this century.

For this Zero Order Draft different sections have been drafted separately. Therefore, the discussion in many of these sections is preliminary and needs to be tightened and shortened. In some cases the discussion overlaps, while there also may be gaps and inconsistencies. Readers are encouraged to comment on the structure of the chapter. In particular, readers should comment on the topics that are covered, whether they can be consolidated, and what should be added or deleted. In the First Order Draft, the materials of each section will be condensed, re-written in such a way as to integrate new sections (e.g., wildfire), and give a more coherent picture of the whole spectrum of issues and themes presented.

Executive Summary

[to be developed]

26.1. Water Management

The water section will start with a description of the broad hydrologic features and regions of North America and how they will be impacted by climate change, summarizing from Chapter 3, Freshwater Resources, WG2, and adding to it as necessary.

26.1.1. Findings from Fourth Assessment Report

Impacts on water resources will be intensified by other stresses such as population growth, land-use change, urbanization, sea level rise, possible intensification of coastal storms. Drying in western USA and southwestern Canada, water quality and health impacts, increased water stresses due to over allocations. Increasing intensity of rainfall, decreasing snow cover, increasing and decreasing annual streamflows, groundwater changes, increasing water demands, high uncertainty in changes in seasonal streamflows, changes in socioeconomic drivers of water consumption and use, adaptation practices and limitations, more

26.1.2. National Analysis

Initially, the water section will be done separately by each nation. In later drafts the material will be condensed and re-written from more of a regional perspective with comparisons between countries and more delineation of anthropogenic and natural forces.

Each national section will begin with an overall assessment of its water resources stresses by major watershed under present and future climates. Existing maps if available will be used.
There will be then an assessment of the recent literature for each nation on how climate change impacts the infrastructure and ecosystem services of water resources as measured by a variety of biophysical and socio-economic metrics. Present or proposed adaptation strategies will also be assessed. This assessment will include the larger systems in each nation such as the Columbia River, the Great Lakes, the Rio Grande, and the Mackenzie but also there will be a special box on the challenges faced by smaller scale, more localized water resources systems that cumulatively serve large populations.

This will be followed by an assessment of the overall adaptive capacity of each nation as measured by economic, social, and natural resources, institutions, and technology. Much of this will reference other sections of the North America chapter and only the unique aspects, if any, related to water management and governance will be assessed.

26.1.2.1. Mexico

Present opportunities and stresses

Agriculture accounts for 77 percent of the water withdrawals followed by 14 % for public supply, 4 % for self supplied industry, and 5 % for thermal electric power plants. (Water Statistics,2010). 63 % of withdrawals come from surface water, the remainder from groundwater. National Water Plan reports efficiencies of water use are relatively low: 33% to 55 % in agriculture, 50% to 70% in cities. Agriculture use is high throughout the nation except in the areas near Mexico City, where urban withdrawals dominate (N Water Statistics). Hydropower, using instream water, generates 13% of the nation's energy (National Water Plan, 2010-2012). Irrigation is supplied to 23 % of the total cultivated area with 93.5 % being done by surface (flooding ?) irrigation, and 4.8 % by sprinkler. There is X % reuse of municipal wastewater.

The population is unevenly distributed with 77% of the population in northern and central regions where there is 31 %% of the water. (NWP 2010-2012).

As can be seen in Figure 26-1, the resulting distribution of people and economic activities results in a most of the central and northern parts of Mexico being presently highly water stressed and the southern regions being of low stress. Stress is defined as ratio of total withdrawals over total renewable resources. In addition, not all regions have adequate water supply and wastewater treatment facilities. Water quality in many places is also low. Freshwater and coastal flooding are also major concerns. Natural arsenic contamination of freshwater impacts 400,000 people in Mexico (WG2, 2007).

[INSERT FIGURE 26-1 HERE
Figure 26-1: Water stress by hydrological-administrative region, 2008. Source: Water Statistics.]

Climate change impacts

Water demands are expected to grow due to population growth, climate change and possible increased production of biofuels. Urban migration will change the types and quantities of water demands. There will be increased demand for irrigation as rainfed systems become more stressed, air temperatures increase, streamflow decreases, and possibly precipitation decreases.

Impacts on public supply, self supplied industry, and thermal electric power plants. To be done. Particularly exploring multiple stresses, sources of vulnerability and adaptive capacity and quantification of multi-dimensional impacts.

Adaptation practices

Proposed adaptation measures (World Bank 2009 Country Note on Climate Change in Agriculture) include more efficient agricultural water use, rainwater harvesting, more heat tolerant crops, integrated water resources management, more use of reclaimed wastewater, soil and water conservation, strengthening indigenous agricultural water management techniques where appropriate such as the use of local tanks (cajetes) on sloping terraces, insurance programs, and improved use of weather forecasting.

Adaptive capacity

As described in Section XXX of this chapter, Mexico's adaptive capacity is weakened by relatively low level of human development (in the 2005 Human Development index, Mexico was ranked 52 out of 177 nations) with approximately 12% of the population living on less than $2 a day and large regional difference in economic and social opportunities. (See Table on page 11 of World Bank 2009 Country Note).

Specific adaptive capacity in water management, however, may be acceptable because Mexico has many national agencies responding to water-related climate change impacts and adaptation. Examples include: the Ministry of the Environment (SEMARNAT), the National Institute of Ecology (INE), the Inter-Ministerial Commission on Climate Change (CICC), and the National Water Commission (CONAGUA). These institutions are effective? As evidenced by ? CONAQUA is particularly strong as evidenced by their national water plans and…..

26.1.2.2. Canada

Present opportunities and stresses

[to be developed]

Climate change impacts

[to be developed]

Adaptation practices

[to be developed]

Adaptive capacity

As described in Section XXX of this chapter, on the whole, Canada is a wealthy nation with high levels of education and technology and strong institutions. Challenge is unequal distribution of these assets. Canada is already undertaking some adaption planning. More to come

26.1.2.3. Continental USA

Present opportunities and stresses
(NOTE THIS IS JUST PLACE HOLDER FIGURE AND TEXT)

Terrain in the continental USA varies from coastal lowlands and wetlands to inland mountains, prairies, and deserts.

Figure 26-2 illustrates some stress indicators. The relative sizes of the wedges for an indicator across all regions represent their relative values. For examples, Regions 13, 15 and 16 all exhibit high cumulative stresses and are dominated by the consumptive use indicator. Since the area of the poverty wedge of Region 3 is approximately equivalent to that of Region 12, they both have the same value. As can be seen, the US central plains and southwest are stressed according to these indicators. In addition, many urban areas throughout the USA are creating water stresses.

[INSERT FIGURE 26-2 HERE
Figure 26-2: Socio-economic indicators under current climate using pie charts.
(NOTE THIS IS JUST A PLACEHOLDER FIGURE)]

Climate change impacts

[to be developed]

Adaptation practices

[to be developed]

Adaptive capacity

Similar to Canada. USA is a wealthy nation with high levels of education and technology and some strong institutions. A challenge is unequal distribution of these assets. Fragmented management of water resources also poses some challenges USA is already undertaking some adaption planning.

26.1.3. Summary and Conclusions

[to be developed]

26.2. Urban Areas

26.2.1. Introduction

High concentrations of populations, economic activities and built environments are among the most important defining features of North America, one of the most urbanized regions of the world. (As of 2010, 80% of the population in US was urban; 69.1% in Canada, and 77.8% in Mexico). These urban centers are presented with higher risks from floods, heat waves, sea level rise and other hazards that climate change is expected to aggravate (UN-Habitat 2011). But in spite of the enormous energy challenges, climate risks and vulnerabilities urban areas are facing, these centers also have opportunities to play pivotal roles in mitigation and adaptation efforts (UN-Habitat 2011). Most North American cities are near tidewater, river water, or both; thus effects of climate change will likely include sea-level rise (SLR) and/or riverine flooding (Weiss et al., 2011). Processes of concern in the AR4, confirmed in most recent scholarship, include aging populations (Lutz et al., 2008), existing and potential impacts of climate hazards on aging infrastructures (Doyle et al., 2008; Karl et al., 2009) and transportation and urban centers dependence on water, food, hydropower, biodiversity and other ecosystems services provided by their hinterlands. Climate change offers many adaptation opportunities (e.g., water technologies and crop insurance) in water scarce areas such as Arizona.

26.2.2. Observed and Expected Changes in Relevant Climate Trends

Urban areas present a unique set of potential climate change impacts. Because of the concentration of population, energy use and emissions, much of the air quality risk lies in urban areas where local-scale surface-atmosphere dynamics (such as related to the urban heat island effect) can dominate the occurrence of air stagnation events. The response of local-scale precipitation and atmospheric circulation to multiple forcings from elevated global greenhouse concentrations, changes in local and regional land cover, and local- and region-scale radiative effects of short-lived atmospheric species remains poorly understood.

The urban heat island effect, which registers differences among urban neighborhoods (Harlan et al., 2008) also makes cities more vulnerable to heat waves than surrounding areas in the same climate regime. Climate model simulations suggest that increased greenhouse forcing will lead to increases in the occurrence of hot extremes throughout North America. These increases result in part from mean warming shifting the temperature distribution, thereby increasing the occurrence of temperatures above a particular critical threshold. In some areas, these increases also result from a change in the temperature distribution, with spatial variations in the magnitude of intensification of extreme hot occurrence being influenced by changes in the large-scale atmospheric circulation and by fine-scale surface-atmosphere interactions. However, research also suggests that the occurrence of local-scale extreme hot events can be reduced by modifying the reflectivity of the urban landscape (e.g., by painting roofs white, Akbari et al., 2009). This modification can potentially also reduce the local energy demand for cooling and decrease the planetary albedo, presenting a possible mitigation-adaptation co-benefit.

Recent research also suggests that the urban areas could be particularly vulnerable to flooding because the urban landscape decreases infiltration (and thereby increases surface runoff). Theory [and] climate model experiments, and observations suggest that warming of the atmosphere and ocean will result in acceleration of the hydrologic cycle that would bring both increased precipitation intensity and more prolonged dry periods. However, understanding of the effects of this global-scale acceleration on the hydrologic regime of particular areas of North America varies. For instance, while drying of the southwestern U.S. and northern Mexico appears robust, the response of the more variable central North America is less certain.

Current findings point to significant regional variation in climate hazards across and within cities (Romero-Lankao et al., 2011 for Mexico). Urban areas are already being faced with an array of hazards, some related to climate change and others that are not (e.g., industrial, technological, McGranahan et al., 2007, de Sherbinin et al., 2007, Satterthwaite et al., 2009), but together these hazards may present a complexity that will increase societal impacts. For instance, in Philadelphia (US), increasing salinity levels of the Delaware River could negatively impact power stations, water treatment plants, food and beverage manufacturers and oil refineries (Sharp 2011[9]). Heat coalesces with urban heat islands and built landscapes (Harlan et al., 2008), or land use changes coalesce with wildfires (Radeloff et al., 2005; Brenkert-Smith 2010).

26.2.3. Observed and Predicted Social and Economic Impacts

Climate variability and change already have a variety of implications for urban dwellers, buildings, economic sectors (e.g., industry, retail and commercial services) and on the network-infrastructures, such as energy, waste water and transport systems (Gasper and Ruth 2011). For instance, severe weather events including heavy precipitation, storm surges, flash-floods and wind can put at risk the built environment, including homes and places of business (Jonkman et al., 2009, Collins et al., 2009, Comfort 2006, Kirshen et al., 2008, Romero-Lankao 2010). They also disrupt and cause lasting damage to highways, seaports, rivers, bridges and other components of the transportation systems that urban centers depend on (Wright and Hogan 2008). They affect such infrastructures as water supply, sanitation and energy provision, and can have implications for the insurance industry and its beneficiaries by increasing the costs of insurance coverage (see section 26.8; Mills, 2005, and Kovacs, et al., 2001). They can negatively affect not only retail and commercial services, or tourism (ski industry Scott et al., 2007), but also industrial facilities, especially if they are located in risk prone areas or they depend on climate sensitive inputs (Mendelsohn et al., 2004; Bin et al., 2007).

Although case studies sometimes focus on economic, social or ecological impacts individually, research increasingly emphasizes their interrelated nature (Gasper and Ruth 2011). For instance, under current financial constraints at the local level, economic losses from adverse climate events can reduce resources available to address social issues, and by doing so pose serious threat to urban livelihoods (Kundzewicz et al., 2009).

Some studies have already explored the future impacts of climate change on urban areas. For instance, significant portions of the built environment and of such infrastructures as road and rail networks are at risk in Boston, Washington, DC, Maryland, Virginia, and North Carolina [Bin et al., 2007; Kirshen et al., 2008, Gallivan et al., 2011, 21]. Seven of the ten largest ports at risk from sea level rise are located in the Gulf of Mexico [22] (USGAO 2007; Conrad 2010; Nicholls et al., 2008). Climate change will increase ozone-related mortality in New York (Knowlton et al., 2008) and other urban centers (Jacob and Winner 2009).

26.2.4. Urban Vulnerability, Adaptive Capacity, and Resilience

A focus solely on the impacts, hazards and affected sectors does not allow an understanding of the whole array of multilevel dimensions and determinants involved in planning for and adapting to climate change at the urban level (see Table 26-1).

[INSERT TABLE 26-1 HERE
Table 26-1: Some Dimensions and determinants of urban vulnerability (Romero-Lankao 2011).]

For urban populations, class and social differentiation are key determinants of urban risks and vulnerabilities. Rather than being equal, climate risks and vulnerabilities are unevenly distributed in at least two ways. First, a process by which economic elites of urban areas are able to monopolize the best land and reap the rewards of environmental amenities such as clean air, safe drinking water, open space, and tree shade (Morello-Frosh et al., 2002; Harlan et al., 2006 and 2008; Rudell et al., 2009). Second, although wealthy sectors are moving into risk prone coastal and forested areas (Collins 2005, Collins 2008), and although beyond a certain threshold hazards can affect both rich and poor alike (Romero-Lankao and Borbor Cordova 2011), climate risks tend to be disproportionally borne by the poor or otherwise marginalized members of society, such as ethnic minority groups (Cutter et al., 2008; Collins et al., 2009). Particularly in Mexico, peri-urban areas are being inhabited by marginalized populations, with inadequate services, a portfolio of precarious livelihood mechanisms, and the absence of appropriate risk-management institutions [Aragon-Durand 2007; Eakin et al., 2010; Monkkonen 2011].

Certain processes of urban change have relevance for understanding and managing climate risks. First, as mentioned previously urban populations are expanding onto low lying coastal areas or onto land with agricultural or natural protection potential, or onto land at risk from floods, storms and industrial hazards (Boruff et al., 2005; McGranahan et al., 2007; Collins 2009). Second, and in contrast with US and Canadian cities, large sections of the population in Mexico and along the US-Mexico border live in housing constructed informally – with no attention to health and safety standards needed to respond to hazards, and with no insurance (Aguilar and Santos 2011; Collins et al., 2009).

Third, some characteristics of the urban built environment (e.g., heat island effect, high levels of atmospheric pollutants) can amplify climate related risks (Rudell et al., 2009, Harlan et al., 2006, Romero-Lankao et al., 2011). For example, the large, impermeable surfaces and concentration of buildings characteristic of cities can disrupt natural drainage channels and accelerate run-off (Walsh et al 2005). The resulting damage from floods can be much more catastrophic if settlements lack drainage or waste collection systems. Although, this may not be as big problem in Canadian and US cities that do not have the very large deficits in infrastructure characteristic of developing countries, many of these infrastructures are in need of major upgrades or repairs. Features of the built environment are a problem for many Mexican cities. With all their dynamism, high levels of integration in the global economy and presence of a strong and creative middle class (Hardoy and Romero-Lankao 2011), Mexican urban areas are still faced with deficits in roads, water and sanitation provision (Niven et al., 2010; Hardoy and Romero-Lankao 2011), as well as with high levels of poverty and informality (Smolka and Larangeira 2008). More than 40 percent of the urban population in Mexico is employed in low productivity and informal sectors; in addition, 34.1 percent of the poor and 15.1 percent of the extremely poor are located in urban centers (ECLAC 2007). This means that while adequately served cities are mostly faced with the challenge of expanding their infrastructures and buildings, or of enhancing their capacity to anticipate and manage extreme-weather events, many Mexican cities have the additional burden of overcoming development deficits.

26.2.5. Urban Climate Responses

Some urban authorities in North America[1] are starting to acknowledge the local implications of climate change and are adapting, i.e., introducing technical, physical and regulatory actions in such relevant systems of interest as housing, infrastructures and services, emergency response, infrastructures, health and the built environment (Table 26-1, column 2). Some adaptation programs have involved the development of "integrated" climate change strategies, e.g., New York (Rosenzweig et al., 2010), and myriad "individual projects" for reducing climate risk (e.g., Mexico City). Yet, for many cities, most of the discussion is still on what cities should do rather than on what they are actually doing to adapt to climate change (Dodman et al., 2011).

[INSERT FOOTNOTE 1 HERE: E.g., Boston, New York, Los Angeles, US., Chicago, Toronto, Mexico City, British Columbia and more to come (Anguelovski and Carmin 2011; Romero-Lankao 2007 and 2011; Zimmerman et al., 2011, Coffee et al., 2010; more to come).]

Adapting urban areas to climate change is complicated by the fact that it is undertaken at different temporal, spatial and sectoral scales, thus requiring a careful assessment of the different layers involved in land use planning, housing, emergency responses and their effects on the determinants of urban vulnerability and adaptive capacity at different levels (e.g., city and individual, Table 26-1). This planning needs to go beyond designing climate action plans or allocating responsibility to departments, such as environmental agencies that are frequently made responsible for managing climate issues (e.g., Mexico City, Romero-Lankao 2007) but do not have the decision making power nor the resources available to address all the dimensions involved. It requires actions not only at the governmental level, but also in the ways that bring businesses, grassroots organizations and individuals into the process to perceive and respond to climate change, e.g., New York, Los Angeles, Mexico City, Vancouver (Croci et al., 2010; Schroeder and Bulkeley 2008; Romero-Lankao 2007; Burch 2010).

Urban populations have long had to cope with a wide range of risks to their economic activities, lives and livelihoods (Romero-Lankao and Gnatz, 2011). Measures such as private or governmental insurance (Browne, M. and R. Hoyt, 2000; Ntelekos et al 2010, section 26.8), safe saving schemes (common in Mexico), reinforcing homes to withstand extreme weather (Simmons, K. and D. Sutter. 2007) or diversifying livelihoods, for instance, through circular migration (Newland et al., 2008; S. Rose and R. Shaw, 2008) become the most frequent type of response to climate hazards.

Community based adaptation, NGOs (ICLEI, c40, etc.) and grassroots organizations have importance in urban adaptation for at least two reasons: they help address the limitations or inadequacies of governmental intervention (e.g., in enhancing the creation of saving schemes or the provision of infrastructure and services); they can become an important tool in the enhancement of resilience to extreme weather events whose timing and magnitude are likely to become less predictable (Colten et al., 2008).

However, community based adaptation and grassroots organizations are faced with constraints given by the [immense] high cost, energy and time required to construct, develop and maintain the key determinants of resilience for the inhabitants of urban centers, namely infrastructures and services, warning systems and emergency preparedness.

26.2.6. Adaptation, Mitigation, and Urban Development

Climate change impacts have implications for existing and future infrastructures, economic activities and populations and will require incremental and transformational adaptations. Examples of the later are movements of land uses and investments away from coastal, riverine, forested and other risky areas, or shifts in directions of urban development to different economic sectors or land uses. Relationships also exist between urban development and adaptations to reduce the impacts of climate change. Many cities that are developing adaptation actions have existing deficits in infrastructure (e.g., insufficient coverage, need of major upgrades and climate proofing), services (health, education), and institutional capacity. Other cities lack willingness to address adaptation issues (references).

There are both synergies and trade-offs between actions addressing the mitigation challenge and other policy dimensions (industrial development, energy, health, air pollution; Hamin and Gurran 2009; Laukkonen et al., 2009). As illustrated by Mexico City, Denver (US), New York and Los Angeles, climate change mitigation is an outcome of efforts driven by economic security and local concerns, or simply by the need to be at the forefront of initiatives among a peer group of city leaders (Romero-Lankao 2007; Rosenzweig et al., 2010). Policies addressing other environmental and social problems, such as air pollution (Harlan and Ruddell 2011), or provision of shelter to the poor (references), can often be adapted at low or no cost in order to reduce GHG emissions and improve the health of the population simultaneously.

26.3. Human Health

This section will cover health risks and management; changing patterns vector born diseases; heat stress; air quality (including ozone, fires, and pollen); water quality; storm events; and co-benefits, tradeoffs, and mitigation-adaptation issues.

26.3.1. Key Findings from Previous Assessments

Current sensitivity/vulnerability

- Many human diseases are sensitive to weather, e.g.,
- Water-borne (and to a lesser extent, food-borne) infectious diseases exhibit seasonal and inter-annual variations that are partially related to variations in precipitation and/or temperature.
- Several important vector-borne diseases, including West Nile virus, Saint Louis encephalitis, dengue and Lyme disease, exhibit temporal and spatial patterns relating in part to ambient temperatures and/or precipitation.
- Extremes of temperature are directly associated with increased morbidity and mortality.
- Air pollution remains an important health challenge in and around urban areas throughout N. America, with temporal variations strongly dependent on weather.

Key future impacts and vulnerabilities

- Risks from climate change will be strongly modulated by changes in health care, technology, and population demographics including age.
- There is high confidence that warming temperatures will lead to more intense heatwaves.
- Safe levels of ozone air pollution will be more difficult to achieve under a changing climate.
- Health risks related to wildfires could increase.
- Pollen is likely to increase with elevated temperature and atmospheric CO2 concentrations.
- The northern range of tick-borne Lyme disease could shift north under a warming climate.
- Urban settlements located on hilly ground with loose soil structure could be vulnerable to landslides associated with heavy rains.

26.3.2. Observed and Expected Changes in Relevant Health Risks

Here we describe current climate-related health risks in NA, reviewing key recent evidence. We then discuss how these risks could change with changing climate, drawing on emerging literature on scenario-based or other approaches.

Extreme storms

Climate variability and change enhance flooding risks from extreme inland and coastal storms. Projected increases in duration and amount of rain as well as extreme wind present risks of flooding and damage to critical infrastructure, with immediate as well as delayed potential for human health impacts. While the connection between hurricanes and climate change is not fully understood, general circulation models generally predict increases in precipitation along with disproportionate frequency of extreme events. [Climate model systems of Atlantic hurricane activity find that warming temperatures of the 21st century may decrease frequencies of Atlantic hurricanes and tropical storms while simultaneously increasing near-storm rainfall and intensity (Knutson et al., 2008). Hurricane intensity may increase, but frequency may decrease (see Box 26-3).

Health impacts of heavy storm events depend on the interaction between hazard exposure and characteristics of the affected communities (Keim, 2008). Coastal cities' low-lying infrastructure and dense populations can create vulnerabilities related to communications, healthcare delivery, and evacuation. Potential public health impacts include direct effects (eg: death and injury) and indirect, long-term effects on contamination of water and soil, vector-borne diseases, respiratory health and mental health. Infectious disease impacts from flooding include creation of breeding sites for vectors (Ivers et al., 2006) and bacterial transmission through contaminated water sources causing gastrointestinal outcomes. Additionally, chemical toxins can be mobilized from industrial or contaminated sites creating exposure pathways through standing water and recreation/green spaces (update: Euripidou, 2004). Elevated indoor mold levels associated with flooding of buildings and standing water have been identified as risk factors for cough, wheeze and childhood asthma (update: Jaakbola, et al., 2005; Bornehag, et al., 2001). Mental health impacts have been among the most common and long-lasting post-disaster impacts. Stress of evacuation, property damage, economic loss, and household disruption were some of the triggers identified in the

Gulf Coast and Midwest region (cite). Coordinated research identifying geographic, infrastructural and population-based vulnerability factors at local and regional levels is urgently needed for preparedness planning.

Heat effects

A large body of literature in North America has associated high temperatures with increased death risks (O'Neill and Ebi 2009; Anderson and Bell 2011; etc etc). In addition a small but growing literature has shown heat effects on morbidity outcomes (e.g., Knowlton). Global warming is shifting the overall temperature distribution higher in the U.S., and increasing the frequency of heat waves ((Meehl & Claudia, 2004). However, projecting future public health consequences of gradual climate warming is a challenging task, due in part to uncertainties in the nature and pace of adaptations that populations and societal infrastructure will undergo in response to long-term climate change (Kinney et al., 2008). Additional uncertainties may arise from changes over time in population demographics, economic well-being, and underlying disease risk, as well as in the model-based predictions of future climate and our understanding of the exposure-response relationship for heat-related mortality. A further issue of importance in considering potential future impacts of warming temperatures on mortality is that of winter mortality. It is widely observed in N. America that mortality rates are on average higher in the cold months of the year relative to other periods. However, what is not yet clear is the extent to which winter mortality is directly related to cold temperatures vs. seasonal factors such as respiratory infections and exacerbation of cardiovascular disease. Deaths directly attributed to cold temperatures might be expected to diminish as winters become warmer. However, seasonal-related deaths may not so diminish. Indeed, winter mortality rates expressed as a ratio to non-winter mortality rates are similar in different climates, suggesting that the winter mortality phenomenon is relatively insensitive to climate (cite).

Air quality

Poor air quality results from a combination of unfavorable weather conditions and high levels of emissions (Jacob and Winner 2009; Kinney 2008). Ozone and fine particulate matter are two classes of air pollutants which have been associated with adverse health effects in many locations around the world at concentrations commonly observed in and around urban areas. Ozone and PM interact with solar and terrestrial radiation, and are recognized as important participants in climate forcing. In addition, climate variability impacts the concentration of these pollutants in the troposphere. Because of the double-sided role of these air pollutants, the effect of climate change of surface air quality is often framed in the broader context of climate-chemistry interactions (cite WG I here). Weather and climate play important roles in determining patterns of air quality over multiple scales in time and space owing to the fact that emissions, transport, dilution, chemical transformation, and eventual deposition of air pollutants all can be influenced by meteorological variables such as temperature, humidity, wind speed and direction, and mixing height (Kinney 2008).

Since AR4 there has been a substantial expansion of the modeling literature examining climate influences on air quality in North America, particularly for ozone (Zhining Tao et al. 2007; Kunkel et al. 2007; Holloway et al. 2008; Jin-Tai Lin et al. 2008; Nolte et al. 2008; Shiliang Wu et al. 2008; Avise et al. 2009; J. Chen et al. 2009; Dawson et al. 2009; K.-J. Liao et al. 2009; Racherla & Adams 2009; Jin-Tai Lin et al. 2010; Tai et al. 2010) Most such studies link climate and chemistry models to simulate surface air pollution concentrations under various scenarios of climate change and air pollution emissions. Findings suggest that surface ozone concentrations in North America will tend to increase somewhat under future climate change scenarios, holding everything else constant. However, some locations for some modeling studies show decreases, and there is little consistency in the regional changes in ozone related to climate change. The literature for climate change and PM2.5 is smaller and less consistent (Kuo-Jen Liao et al. 2007; Avise et al. 2009; Dawson et al. 2009; Pye et al. 2009; Mahmud et al. 2010. The uncertain sensitivity to climate change in the case of PM2.5 reflects in part the complexity of the dependence of different PM2.5 components on meteorological variables, and in part on the coupling of aerosols to the hydrological cycle which is not well represented in GCMs (Racherla & Adams, 2006; Pye et al., 2009) . Several recent studies have taken air pollution estimates from coupled climate/chemistry models to assess potential future health impacts (Bell et al.

2007; Knowlton et al., 2008; E. Tagaris et al. 2009; E. Tagaris et al. 2010; Chang et al. 2010). A common theme from these studies is that impacts could be greatest in locations that already face serious air quality challenges.

Wildfires

Wildfires are clearly dangerous to people who come in close contact to them. Potential direct effects include injury and respiratory effects from smoke inhalation, with firefighters at increased risk (Reisen et al., 2009; 2011; Naeher et al., 2007). Adverse mental health outcomes are also a concern for fire victims. Studies suggest that victims of fire disasters are at risk of psychological disorders such as post-traumatic stress disorder and depression (Marshall et al., 2007; Laugharne et al., 2011). At the population level, however, the indirect effects of wildfire become increasingly important, and a particular concern is the impact of wildfire smoke on respiratory diseases. Depending on meteorological conditions, this smoke can travel hundreds of kilometers from its source and is easily visible in satellite images taken during wildfire events. Wildfire smoke, like other combustion byproducts, contains a mixture of particulate and gaseous material, including a number of products known to adversely affect human health (Naeher et al., 2007; Stefanidou et al., 2008). In particular, wildfire smoke can greatly increase population exposures to particulate matter (PM). During the 2003 Southern California wildfires, two sites in San Diego County recorded 24-hour concentrations of $PM_{2.5}$ in excess of 240$\mu g/m^3$ (Delfino et al., 2009). The 2008 California wildfires, which were located in Northern California, resulted in hourly levels of $PM_{2.5}$ reaching 160$\mu g/m^3$ in the city of Tracy (Wegesser et al., 2009). One study has shown a direct contribution of wildfires to summer mean ozone concentrations in rural locations of the western United States (Jaffe et al., 2008). Epidemiological studies in N. America on associations between wildfire air pollution and health outcomes have consistently found associations between wildfire PM and respiratory distress, particularly among asthmatics and sufferers of chronic diseases such as COPD (Delfino et al., 2009; Kunzli et al., 2006; Vora et al., 2011).

Pollen

Exposure to certain pollen types has been associated with a range of allergic outcomes, including exacerbations of allergic rhinitis (Cakmak et al. 2002, Villeneuve et al. 2006), exacerbations of allergic asthma (Delfino et al. 2002), and allergic sensitization (Bjorksten and Suoniemi 1981, Porsbjerg et al. 2002). Pollen concentrations are dependent on both short-term weather and longer-term climate variables. Thus, future changes in temperature, precipitation, and CO2 concentrations associated with climate change could lead to changes in the pollen season. If pollen seasons are altered, it can be hypothesized that these changes would also be associated with changing patterns of allergic disease morbidity.

Consistent with recent increases in temperatures, many studies have indicated that the pollen season is beginning earlier in the year for a number of species (Ariano et al. 2010, Clot 2003, Emberlin et al. 2002, Frei and Gassner 2008, Levetin and Van de Water 2008, Rasmussen 2002, Teranishi et al 2006). Some pollen types, such as ragweed, also have shown an increase in season length (Ziska et al. 2011, Ariano et al. 2010). However, research has been limited by shortcomings of available pollen databases

Numerous studies have shown that higher temperature and greater precipitation in the months prior to the pollen season lead to increased production of many types of tree and grass pollen (Lo and Levetin 2007, Reiss and Kostic 1976, Gonzalez Minero et al. 1998, USEPA 2008). Furthermore, ragweed pollen production has been observed to increase in response to increased temperatures and concentrations of atmospheric carbon dioxide (Singer et al. 2005, Wayne et al. 2002, Ziska and Caulfield 2000, Ziska et al. 2003). More studies are needed to examine the effect of carbon dioxide concentrations on woody plants such as trees.

Waterborne diseases

Need some Mexico and Canada text: In the United States, three common waterborne diseases alone – cryptosporidiosis, giardiasis, Legionnaires' disease – cost the health care system as much as $539 million per year

(CDC 2010). People can contract illnesses through a number of pathways – consumption of drinking water, direct contact with recreational or floodwaters, person to person, and inhalation of aerosols containing bacteria. Furthermore, even though more than 200 million Americans have direct access to disinfected public water, estimates suggest that waterborne pathogens can cause anywhere from 12-20 million cases of illnesses per year (Reynolds, Mena, & Gerba 2008; Bridge et al. 2010). These high figures still likely underestimate the actual waterborne disease burden since many cases, typically gastrointestinal illness, go unreported (Rose et al. 2001). Though healthy adults perceive gastrointestinal illnesses as a transient nuisance, it can be fatal to the susceptible populations: infants, elderly, pregnant women, or immunocompromised individuals (e.g., AIDS, cancer, or organ transplant patients) (Rose et al. 2001). In fact, 85% (46) of the deaths from the 1993 cryptosporidiosis outbreak in Wisconsin occurred among patients suffering from AIDS (Craun et al. 2006).

Vectorborne infectious agents – Lyme disease; west Nile; dengue; is Malaria present in Mexico

26.3.3. Vulnerability, Adaptive Capacity, and Resilience

Vulnerability dimensions under current and future climates; within and between countries. Age, SES, macro-scale phenomena

Adaptation strategies with a couple of case studies showing success, most likely related to heat warning systems.

26.3.4. Health Dimensions of Mitigation Actions

What near term benefits or disbenefits for health can be anticipated in response to mitigation actions? Air quality; obesity/cardiovascular risks/physical activity related to differential food sources and/or urban forms.

26.4. Climate Impacts on Ecosystems and Their Socioeconomic Implications

This section explores interactions between climate change effects on ecosystems and society by examining forests and other vegetation affected by pine beetles and fire, salmon, and coral reefs.

26.4.1. Forests Infestation

Pine beetle

Recent outbreaks of Mountain Pine Bark Beetles (MPBB) in the Western Rockies of the USA have devastated the lodge-pole pine forests from Alaska down to Colorado. In addition, outbreaks have emerged in the high elevation areas of the Rockies in the white bark pine systems and have resulted in massive die offs of these highly vulnerable species. The climate controls on over-wintering populations of the mountain pine bark beetle have been overcome by recent warmer winters allowing a greater number of larvae to survive. This increase survivorship and the associated longer growing season for the adults have permitted severe outbreaks to take place so that numbers are large enough to kill a number of the host trees. The outbreak in the white bark pine system presents additional threat of extinction of populations of white bark pine due the long-lived nature of this species and the difficult germination requirements. This has further implications to other species of this ecosystem type, such as the grizzly bear which depends on the seed crop of the white bark pine for over wintering forage.

The MPBB infestation in British Columbia, Canada has resulted in mortality in over 7 million hectares of mature lodgepole pine (Aukema et al 2006). Climate change has contributed to the extent and severity of this outbreak (Kurz et al. 2008a). The widespread mortality of lodgepole pine (Pinus contorta var. latifolia) caused by the beetle has significant implications for BC's timber supply and Canada's carbon (C) budget (Brown et al. 2010). Such outbreaks convert forests from carbon sinks into carbon sources, by reducing carbon uptake from healthy trees, and emissions from the decay of dead trees (Kurz et al 2008a). [One study forecasts that Canada's forests can become a net carbon source as a result of increasing number and severity of pest infestations as well as fires (Kurz et al 2008b). Spatial studies of the outbreak show many simultaneous localized outbreaks rather than a single source that spread, strongly associated with the location of conservation parks (Aukema et al 2006), and older stands experiencing higher mortality rates (Brown et al. 2010). Available population models and climate forecasts indicate an expansion of suitable conditions for the bark beetle into higher latitudes and elevations (Bentz et al 2010). The estimated impact on the carbon budget is significant, with one study showing a contribution of an additional 270megatonnes of carbon into the atmosphere as a result of the outbreak (Kurz et al 2008a). *D*eferring the harvest of stands with significant levels of secondary structure could prevent MPB-attacked forested areas from becoming C sources (Brown et al. 2010).

In Colorado, tree mortality from the beetle covers approximately 2 million areas, including all of the state's mature lodgepole pine and some other forest types. The MPB has affected approximately 694,150 acres of lodgepole, limber, and ponderosa pine in Wyoming.

The effect of mean warming shifting the temperature distribution towards decreased occurrence of cold extremes is robust, and suggests that pest ranges could expand poleward and upward in elevation in North America in response to elevated greenhouse forcing. However, the effect of changes in the large-scale atmosphere and ocean circulation is less robust, as the atmospheric conditions that create extreme cold events exhibit substantial inter-annual variability and are strongly coupled to the state of the ocean. Further, snow cover exerts an important influence on the surface energy budget. Although local decreases in snow cover associated with winter warming have been shown to amplify greenhouse-induced decreases in the occurrence of extreme cold events, potential feedbacks between changes in atmospheric circulation and snow cover are not completely understood.

Section 26.7 assesses the social-ecological impact on livelihoods and risk associated with changing disturbance regimes in these mountainous systems. Considerations of water flow, habitat changes, recreational usage, and timber harvest are issues being evaluated across the Western Mountain regions of the US. In addition, the increased risk associated with fires and altered hydrological flows are of great concern across the periurban areas of the region under continued climate change.

The socioeconomic impacts of the outbreak have been significant. In the short term, the infestation has led to a significant increase in forest harvests to remove merchantable timber before it is affected by the outbreak, but this temporary boom will diminish, and regional economies will either need to transition into other sectors or face a net decline in economic activity. Anticipated future timber supply reductions vary from -10 to -62% (Patriquin, Wellstead and White (2007). Patriquin, Wellstead and White (2007) employed a computable general equilibrium framework to estimate the economic impact. In this comparative study, the region most sensitive to forestry supply changes indicated that for every 1% change in forestry exports, net domestic product (NDP), royalties, labour income and employment to changed by 0.88%, 1.12%, 0.78% and 0.54% respectively. Impacts vary by region depending on degree of economic dependence on forestry. Parkins and MacKendrick conducted an extensive comparative study of six communities in the affected region (MacKendrick and Parkins 2005; Parkins and MacKendrick 2007; Parkins 2008). According to Parkins (2008).

The current infestation involves direct impacts on more than 30 communities and 25,000 families who rely on the forest industry for their livelihood (Ministry of Forests, 2006). Within these communities, at least 30% of direct and indirect income is derived from forestry, and over the long term, when salvage of dead trees becomes infeasible, analysts expect that 25% or more of the present income level in these communities will be lost (Ministry of Forests, 2006).

This study indicated high variability in Vulnerability, resulting from variability in both the level of exposure, and the social, political and economic conditions characterizing the communities. Generally communities with higher degrees of economic dependency and lower socio-economic conditions were more vulnerable. According to household surveys in all six communities, levels of trust in government and industry are low, which may have a deleterious impact on the implementation of adaptation strategies. However, Since the outbreak, several Beetle action coalitions have emerged, which Parkins (2008) considers to be a promising step, in large part because they have been planned to enhance future local response capacities in a manner that empowers local residents to participate in negotiation with provincial and federal governments.

_____ START BOX 26-1 HERE _____

Box 26-1. Insect Outbreaks and Biodiversity

Insect outbreaks also affect the biodiversity of the forest ecosystem. BC's interior forests support over 185 wildlife vertebrate species, about 24% of which are cavity-nesters. But over the long term, insect infestations result in a decline in the supply of forest insects and old trees necessary to the survival of cavity nesters (Martin, Norris and Drever 2006).

[INSERT FIGURE 26-3 HERE
Figure 26-3: Title? Source: Natural Resources Canada, http://mpb.cfs.nrcan.gc.ca/map_e.html.]

_____ END BOX 26-1 HERE _____

_____ START BOX 26-2 HERE _____

Box 26-2. Survey on Pine Beetle

[If published in sufficient time, we will include results of a survey in Colorado and Wyoming on public attitudes towards the pine beetle infestation.]

_____ END BOX 26-2 HERE _____

26.4.2. Wildfires

Forest fires can have a natural or human activity. For a long time the fire regime in Canada and USA have been of low intensity due to the high security and surveillance that these countries have on their ecosystems. Historical fire suppression efforts have contributed to an accumulation of fuels and the fire became increasingly severe. In the boreal forest; there has been a doubling of the area burned for the past 20 years. In North America prescribed burning is an essential part of the management and maintenance of these ecosystems (Amiro et al. 2003)

The increase in the last decades of wildfires indicates that these phenomena are related but not isolated to ENSO or PDO phenomenon (Hessl et al 2004, Villers & Hernandez, 2007). It is clear that for some cases, fires occur with great regularity and are altered by wind anomalies as in southern California, where large conflagrations are usually associated with the annual wind events that follow the long spring and summer drought (Keeley J 2004) In the Mexican case, increasing human presence (agricultural areas adjacent to forests or land tenure conflicts) has undoubtedly augmented the probability of ignitions during the fire season, mainly between March to May each year (Villers et al.2006).

The origin of fires and fire management policies in USA and Canada contrast with to what happens in Mexico. [While the first countries fire is part of natural processes, lightning and sometimes in specific areas human irresponsibility,] in Mexico there is [massive] very high fire risk due use of fire in agricultural techniques or intentional fires in urban areas close to forests, land tenure conflicts, poaching practices and carelessness of improperly put out bonfires in protected areas. (CONAFOR 2010). Field et al. (2007) noted that higher temperatures increased the period without snowcover drought, leading to more fires.

26.4.3. Climate and Pacific Salmon

Climate is integral to Pacific salmon habitat. As coldwater ectothermic species the range and distribution of Pacific salmon are limited at their southern ends by extreme high temperatures both in freshwater (add citations) and marine environments (Welch et al 1995, Welch et al 1998a, Welch et al. 1998b, Azumaya et al 2007). Extreme cold growing season temperatures define the northern end of the Pacific salmon range in the Arctic (cite?). The regular seasonal cycle of climate and related impacts on streamflows, stream temperatures, and productivity patterns in estuaries and the ocean also dictates many of the seasonal life history patterns observed in different salmon populations around the Pacific Rim. Finally, variations in climate between years and decades have been linked with changes in salmon productivity at scales ranging from the entire N. Pacific (Beamish and Bouillon 1993), Alaska (Hare and Francis 1995), and for the entire range of Pacific salmon in Western North America (Mantua et al. 1997).

Future climate changes are expected to continue impacting Pacific salmon habitats in freshwater, estuaries, and the ocean in profound ways (Welch et al 1998a,b; Battin et al 2007, Crozier et al 2008, Mantua et al 2010, etc.). At the broadest scale, there are good reasons to expect future climate warming will further degrade salmon habitat, productivity and abundance at the southern end of their range while doing the opposite at the northern end of their range. Additionally, the range limits of salmon species are likely to shift poleward and expand into more Arctic watersheds than currently host self-sustaining populations. However, within those limits there will likely continue to be highly diverse population-specific responses that include both increases and decreases in productivity and abundance, and perhaps shifts in the numerically dominant species within individual regions or watersheds. Populations that have especially brief freshwater rearing periods, including pink salmon, chum salmon, and “ocean-type” Chinook salmon, may fare especially well in freshwater habitats that become increasingly stressed by future climate change. In contrast, populations with extended freshwater rearing periods, including stream-type Chinook salmon, sockeye salmon, coho salmon, and steelhead trout, may suffer most where their freshwater spawning and rearing habitats are especially degraded by future climate changes.

The specific economic effects of climate-driven change in salmon resources are highly uncertain, given the uncertainty about how climate change may affect specific salmon resources. We can however make some general inferences about the nature of these effects.

Perhaps the most important point is that all salmon fisheries exhibit high natural variability in returns and catches, both from year to year and also over interdecadal time scales, due to factors ranging from variability in local stream flows to El Niño Southern Oscillation (ENSO) events and the PDO. Examples of this natural variability may be seen in the long-term indexes of Alaska sockeye and California chinook commercial salmon harvests shown.

This natural variability of returns is reflected in the variability of economic indicators of the fishery, as seen in the long-term indexes of the real (inflation-adjusted) value to fishermen of salmon harvests. Both the short-term and long-term economic variability of the industry has been changed and amplified by a wide variety of other economic factors such as dramatic changes in processing and transportation technology, exchange rates, and seafood demand.

The economic implication is that the industries dependent on salmon resources have been and are likely to be continually adapting to both short-term and longer-term natural and economic variability. The longer term trends in species abundance, location, and seasonal timing that may be attributed to climate change will be one more source of variability [to which the industry will have to adapt]. Except at the extreme southern and northern edges of salmon habitat where runs may disappear or new significant runs emerge, the longer-term effects of climate change will likely occur against a backdrop of much greater natural and economic variability. This doesn’t mean that the long term effects of climate change will be neutral or unimportant. But they are hard to predict and will likely to be hard to measure for much of the industry in comparison with natural and economic changes due to shorter duration phenomena. The long-term negative effects are most likely to be felt in the southern range of Pacific salmon.

26.4.4. Coral Reefs

There are important coral reefs in North America for its beauty and biological diversity, both in the Pacific, located on the Tropic of Cancer in the Gulf of California (Hernández et al. 2010) and the Atlantic Mesoamerican reef system, a thousand km barrier reef coral (Iglesias Prieto). The environmental services provided by these ecosystems are refuge areas, breeding and feeding of commercial species, tourist attractions and protection during hurricanes and storms. Due to the fragility of these ecosystems the impacts of coastal development can be greatly reduced through effective planning and regulations and control over human activities such as commercial fishing and mass tourism. (Bozec et al 2008)

26.5. Indigenous Communities

[to be developed]

26.6. Food Systems

Food systems are composed of the interactions between and within biogeophysical and human environments, which determine a set of activities (see section 26.3); the activities themselves (production, processing, distribution, consumption) and a diversity of actors (farmers, private industry, consumers and citizen groups, public agencies) which together are organized in specific technological, political, economic and social-cultural circumstances for food provisioning. The vulnerability of food systems is evident when one or more desired outcomes from food systems are disrupted: food security (access, availability, utilization); social welfare and ecological integrity (Ericksen 2008). Climate change will alter the conditions for food production and may also disturb food processing, food distribution and ultimately consumption activities (Schmidhuber and Tubiello 2007). Given the important role of U.S. and Canadian land use and production outcomes in global commodity markets, and the influence of the North American food processing and distribution industries and infrastructure on international food distribution, how climate change affects the region is important both regionally and globally. Climate change impacts on the North American food systems can be understood in terms of the internal economic, cultural and political significance of the food system within the region, its robustness and ability to withstand shocks and its adaptiveness in face of change. The degree of food trade among the three countries, as well as labor, research and capital defines their vulnerability as partially interdependent.

26.6.1. Production: Vulnerability to Climate Change

Agriculture and food play critical but differential roles in Mexico, the US and Canada. Agriculture represents approximately 1% of GDP in the US and Canada, and just over 4% in Mexico. Agriculture in the United States and Canada and northern Mexico is generally capital-intensive with tendencies toward monoculture. Production and hunting for subsistence purposes is still an active component of the sector for Aboriginal groups of Canada and across Mexico's rural areas. The US and Canada are known for large scale grain production (wheat, corn, sorghum, soy); commercial horticulture production is also a prominent feature of the US western and southern coasts, northwestern Mexico and Canada. Maize (corn) is one of Mexico's most significant crops in terms of land area, production, consumption and value. Tropical commodities such as coffee continue to play an important role. Production of vegetables in controlled environments (greenhouses) is a significant growth sector in both Canada and central and northern Mexico.

Studies of U.S. and Canadian agriculture conducted at large geographic scales anticipate productivity gains for many crops, particularly when the increase in CO2 levels is included (e.g. Hatfield et al 2008). With longer and warmer growing seasons there would be potential to expand the range of warm season crops or to possibility introduce new crops (Nadler and Bullock 2011). Using five different climate change models, Pearson, Bucknell and Laughlin (2008) forecasted increases in growth indices for time periods up to 2099, with an increase in the length of the growing season by 5–7 weeks, but incidences of moisture deficit would also increase. Many such models, however, are based primarily on forecasted increases in temperature, and exclude multiple other factors such as extreme events (e.g. Chen and McCarl 2009), shifts in water availability (e.g. Vano et al. 2010), the introduction of new weed and pest species (e.g. Jackson et al. 2009). Kulshreshtha (2011) argues that previous work has not adequately accounted for the potential impact of increased frequency of extreme events (droughts, floods) and thus the beneficial outcomes of climate change for agriculture may be exaggerated. Researchers are beginning to conduct studies at smaller geographic scales in order to include many of these sources of variation, and drawing far more cautious conclusions.

For example, the Prairie Provinces are the center of Canadian Agriculture, producing approximately 51% of Canadian production (Kulshreshtha 2011). Warming trends and a decrease in frost risk (Wheaton et al 2010) may enhance the yields of some crops, but the decline in snow pack and the risk of new pests and diseases, hotter days during flowering, higher and more intense precipitation, and lack of soil moisture will threaten crop yields (Kulshreshtha 2011). While previous work estimated higher grassland productivity with elevated CO2 (Campbell et al. 2000), warmer temperatures also bring new pests and diseases for livestock and the risk of alien species invading grasslands and pastures (Kulshreshtha 2011). Similarly, while previous work has demonstrated that higher winter temperatures will benefit livestock operators, lowering feed requirements and reducing energy costs (e.g., Rosenzweig and Hillel 1998), other work has highlighted the potential impacts of extreme events on livestock operations ranging from heat waves affecting quality of products, animal productivity and mortality (National Drought Mitigation Center 1998; Adams et al 1999) to the effects of blizzards on infrastructure (Murphy 2009). A study of California agriculture (Costello, Deschenes and Kolstad 2009) concludes that climate change does not have a negative effect on agricultural profits, but this study, similar to many modeling studies, utilized a model that kept water supply and farm prices constant and ignores climate variation and excluded extreme events (e.g., droughts and floods) [and thus must be accepted with caution]. A study of Midwestern U.S. high value groups and dairy (Wolfe et al. 2008) found that fruit yields and milk productivity will decline with higher temperatures and with an increased risk of invasive weeds and insects with milder winter temperatures, but this study did not consider adaptation. [While some operators with the capital to take risks on new crops may be able to take advantage of a longer growing season, overall the impacts of climate change will be negative.] Another modeling analysis conducted for Iowa indicated that expected rainfed corn yield by 2055 could decline by 23%–34%, and the probability that the yield may not reach 50% of the potential yield is between 32% and 70% if no adaptation measures are instituted (Cai, Wang and Laurent 2009).

Building on prior work that indicates generally reductions in grain yields in Mexico (e.g., Conde et al. 1997), more recent work continues to indicate a reduction in land suitable for corn (Rivas et al. 2011) and for grain yields more generally (Lobell et al. 2011). Nevertheless, there are regional variations to this general assessment. Lobell et al. (2005) found that most of the observed increase in wheat yields in Northwestern Mexico, for example, can be attributed to cooling of nighttime temperatures over the last several decades. As with research in the U.S. and Canada, the effects of extreme events introduce greater uncertainty into modeling outputs. One general equilibrium analysis of a simulated significant multi-sector drought in Mexico found that agricultural production would experience losses of output in the range of 12%-14%, affected not only by direct impacts to productivity but indirect impacts due to rising energy costs (Boyd and Ibarrarán 2009). Coffee, an export crop in Mexico, is also projected to experience negative impacts from climate change. One study estimated a reduction of 34% in coffee production by 2020 in major coffee producing regions, indicating that coffee production might not be economically viable for many producers (Gay et al 2006). Increase in the frequency of climate-related disasters will also likely threaten coffee production (Saldaña-Zorilla 2009; Schroth et al 2009). Schroth et al 2009 combined climate change scenarios in the MAXENT model to estimate that land suitable for coffee at lower elevations will decline significantly in the Sierra Madre, increasing pressure on forested land at higher elevations and potentially making the region unviable for the production of high-quality specialty coffee. Overall, there remain high levels of uncertainty on the impacts of climate change, with several studies finding that the multiple predicted causative factors very often seem to cancel each other out and dilute the impacts of climate change on crop yields (e.g. Brassard and Singh 2008).

26.6.2. Fisheries

The habitats of coldwater fish, such as salmon and trout, are very likely to contract in response to warming, while [some] warm-water fishes such as smallmouth bass and bluegill might expand (Janetos et al. 2008). Invasion of nonnative invasive species will threaten resident populations. In Alaska, climate change is already causing significant alterations in marine ecosystems, restricting important fisheries in that state (USGCRP 2009). Historically, warm periods in coastal waters have coincided with low salmon abundance (Crozier et al. 2008). According to one estimate, up to 40 percent of Northwest salmon populations may be lost by 2050 due to climate change (Battin et al. 2007).

26.6.3. Impacts on Quality of Production

Climate change will not only affect yields and productivity, but also the quality of key commodities. The food industry is increasingly competing on claims of quality, particularly in specific niche markets important in the regional economies. Mexican coffee quality, for example, is dependent on a variety of agroecological characteristics including temperature, precipitation and shade cover and thus is potentially affected by drying and warming conditions (Lin 2007). Similarly, the wine industry in the US has experienced trends in increasing temperature, which affects the ripening and sugar levels of grapes. This in turn affects alcohol content and acidity of wines (Jones et al. 2005). Earlier ripening of grapes in California is also expected to impact quality (Hayhoe et al. 2004). The protein content of wheat is also projected to be negatively affected by rising CO_2 and temperatures, potentially affecting the use and value of wheat products (Porter and Semenov 2005). Quality concerns have also been identified with climate change impacts on perennial fruit and nut production in California, potentially leading to higher prices for these products (Lobell et al. 2006).

26.6.4. Producer and Worker Livelihoods and Vulnerabilities

Climate change will affect agricultural employment and labor as well, although in all countries, it must be noted that agricultural producers face multiple sources of climatic and non-climatic stress (Coles and Scott 2009; Eakin 2006; Eakin and Wehbe 2009) and thus climate vulnerability cannot be considered in isolation. While a comparable proportion of the population works in agriculture in the US and Canada (1.9% and 2.8%), in Mexico 13% of the economically active population is in the primary sector (SAGARPA, http://www.sagarpa.gob.mx/saladeprensa/boletines2/paginas/2011B079.aspx).

Farm values and water availability are strongly correlated (Schlenker, Hanemann and Fisher 2007). In some scenarios of increased water scarcity in Washington state production is likely to decline significantly, by as much as 5%–16% annually, according to Vano et al (2010). Other research has highlighted the potential for water conflicts in the Great Plains and Southwest under climate change (Lal, Alavapalati and Mercer 2011 (in Alig). Water rights and access will likely be affected, leaving newcomers (junior rights holders) with a much lower level of security of water access (e.g. Vano et al. 2010). Research in Sonora, Mexico highlights the negative gender implications as water access for horticulture production is reduced and crop productivity declines (Buechler 2009). In many regions water is already being consumed at high levels for agriculture, and options for increased irrigation are limited. For example, in Arizona, a major agriculture-producing state, irrigated agriculture already accounted for 80% of groundwater use and 81% of surface water use as of 2000 (Coles and Scott 2009). [Beyond water, increased costs of farming under a warming scenario may surpass the livelihood threshold for many farmers.] For example, controlling weeds currently costs the United States more than $11 billion a year (Kiely et al. 2004), and this cost is likely to increase as temperatures rise (cite McCarl). Furthermore, the most widely used herbicide in the country, *glyphosate*, loses its efficacy at CO_2 levels that are projected to occur in the coming decades (Wolfe et al. 2007; Hatfield et al. 2008). Warmer temperatures are also expected to increase livestock production costs.

Nevertheless, climate impacts on producing populations will be experienced differently depending on the regional impacts of climate change and the degree of livelihood dependence on production and support structure available (Eakin and Appendini 2008). Research in northeastern Mexico has highlighted the role of economic and crop diversification in mediating the combined impact of climate and market shocks (Eakin et al. 2008; Eakin and Bojórquez-Tapia 2008), indicating that smallholder diversified producers in some cases may have more flexibility in managing climate impacts than medium-scale farmers without access to institutional safety-nets. The lack of institutional safety-nets and access to credit was found to differentiate the high vulnerability to drought of small-scale largely Hispanic farmers and ranchers in Southeastern Arizona to drought from their larger-scale counterparts (Vasquez-Leon et al. 2003). While rainfed producers are generally thought to be more sensitive to climate impacts, farmers planting under irrigation for competitive markets may be exposed to enhanced market risk and higher capital losses (Eakin 2003).

Mendelsohn et al. (2008) used a Ricardian analysis to find that land values can be expected to decline significantly across Mexico with warming temperatures, and that irrigated farms may stand to lose more than rainfed farms in some areas. In a modeling exercise by Feng, Krueger and Oppenheimer (2010), on the basis of historic data, a 10% reduction in crop yields leads to an additional 2% of the emigration population. Other factors held constant, by 2080, climate change is estimated to induce 1.4 to 6.7 million adult Mexicans to emigrate as a result of declines in agricultural productivity alone, although projecting migration is fraught with uncertainty.

It is not only producer livelihoods that are at risk, but also workers. US and Canadian agriculture, particularly horticulture production, is heavily dependent on the support of seasonal farm labor. The livelihoods of these workers are not only susceptible to the impact of climate change on production and thus employment opportunities in US and Canada and other employing regions within Mexico, but also to the impact of climate change on their livelihood opportunities in source communities (Saldaña-Zorrilla and Sandberg 2009).

26.6.5. Adaptation and Adaptive Capacities

There are several adaptation options available for growers. In the Canadian prairies, for example, several pulse varieties are thought to do quite well in the warmer and drier conditions, such as chickpea and lentil which are suited to climatic extremes of frost and drought (Saskatchewan Pulse Growers 2000). Shifts away from production of barley to high-energy and high-protein crops (corn and soybeans) that are better adapted to the warmer climate would benefit Atlantic Canada producers (Bootsma, Gameda and McKenney 2005). Coles and Scott (2009) note the detrimental effects of historic planting of non-native species in grazing lands, suggesting native species will have the greatest tolerance for climatic change.

Adaptation will face significant challenges, however. [While some recent case studies indicate a high level of climate awareness among agricultural communities (Jackson et al. 2009), growers face cognitive, economic, technological, and other obstacles.] Barriers to adaptation include how producers perceive risk and make use of information about climate change (e.g., Frank et al. 2010; Reid et al. 2007); demographic factors such as the increasing age of farmers in all three countries and education levels in some regions (e.g. Eakin and Wehbe 2009); uncertainty in markets, obstacles to organization and the high costs and risks of alternative strategies (e.g., Pittman et al 2010; Coles and Scott 2009). [In Canada, the limited resources that are being allocated to adaptation generally consist of monies previously allocated to mitigation, and officials face numerous challenges in implementation, including competing priorities and uncertainty (Jacques, de Vit and Gagnon-Lebrun 2010).]The 2001/2 drought in the Prairies put existing adaptation mechanisms to the test. Wheaton et al (2007) and Wittrock and Wheaton (2007) found that drought was very costly and disruptive, even with the active application of much adaptation, which suggests an adaptation deficit exists (Wittrock and Wheaton 2007). In the Canadian Arctic, financial resources and capital are often lacking to invest in new hunting technologies and infrastructure, and there is some concern that the erosion of local knowledge and social networks has weakened adaptive capacity (Ford and Pearce 2010).

In Mexico, improved land management and revitalization of traditional risk management institutions hold promise in reducing some degree of climate impacts. In coffee production, agroecological practices have shown in some cases to enhance resistance to moderate rainfall extremes (Holtz-Gim»nez 2002; Lin 2008; Schroth et al. 2009) while offering greater livelihood stability through niche market access (Bacon 2005). Nevertheless, adaptations that favor farm communities may not necessarily favor ecosystems. Shade-grown coffee has benefits for local bio-diversity, while other land uses that may be considered by farmers to replace coffee (e.g., sugar cane; see Hausermann and

Eakin 2008) may threaten biodiversity, as would expansion of coffee into higher elevations that are currently forested (Schroth et al 2009). Reducing the potential negative impacts of farmers' adaptive strategies in sensitive areas may require the use of new institutional arrangements such as payments for forest conservation and restoration from existing government programs complemented by private initiatives and the development of markets that reward sustainable land use practices and forest conservation (Schroth et al 2009). Rather than rely on public instruments to reduce disaster risk in Mexico, farm communities are more likely to rely on economic and crop diversification and migration to mediate climate impacts (Saldana-Zorilla 2009; Eakin 2006; Wehbe et al. 2006).

26.6.6. Climate Vulnerability and Trade Relationships

The food and agricultural sectors of Canada, the US and Mexico are closely linked in trade, and increasingly so since the North American Free Trade Agreement (NAFTA) was signed by all three countries in 1994. This interdependency introduces the possibility that climate change not only may have direct impacts on traded commodities, but also that the region can be affected by changes in policy associated with energy or green house gas mitigation, as occurred in 2007-08 with the diversion of US corn output into ethanol rather than exports to Mexico (Searchinger et al. 2008; Liverman and Kapadia 2010). The 18% increase in the price of tortillas in 2007-08 primarily affected the poor for whom tortilla expenditures represent 10% of food purchases (Valero-Gil and Valero 2008).

Incentives for commercial production and export have also altered regional profiles of climate vulnerability, in some cases increasing climatic risk. For example in Canada, after NAFTA the promotion of higher-quality *Vitis vinifera* varieties of grape in lieu of more winter-hardy French hybrid grape varieties enhanced economic competitiveness but also sensitivity to winter injury (Belliveau, Smit and Bradshaw 2006). In Mexico, participation in irrigated vegetable production for commercial markets may enhance risk of high economic loss for smallholders in face of climate extremes (Eakin 2003; Eakin 2006). Others have found that trade liberalization has exacerbated vulnerability among some Mexican farmers, contributing to a 60% net drop in mean weighted agricultural prices over the past 25 years (Saldana-Zorilla 2009), a situation that has motivated intensification of farming on marginal lands, and farm abandonment.

26.6.7. Food and Beverage Industry

While far less research has been conducted on this part of the North American food system, food and beverage manufacturing and retail is also potentially susceptible to climate impacts through changing energy prices, input availability, changes in food pathogen prevalence, rising production costs in the farm sector, and physical infrastructure risks associated with extreme events. In Canada the food processing industry is the second largest of its manufacturing industries, supplying over 80% of Canada's processed food (Agriculture and Agrifood Canada, 2011). In Mexico it contributes more than 30% of the domestic product of manufacturing industries and generates about 14% of the jobs. Food processing is relatively less influential in the US (constituting approximately 13% of total manufacturing value in 2005, USDA 2010). Nevertheless, food processing in the United States is economically and geographically concentrated in relatively few enterprises, raising concerns over the capacity of the sector to innovate and maintain efficiency (USDA 2010), as well as the susceptibility and resilience of the food system more broadly to shocks, as has been explored in the context of the threat of bioterrorism (Cupp et al. 2004). In both the US and Canada, the food retail and distribution subsector is also heavily concentrated and as the primary interface between consumers and the food supply, some large US-based retailers are moving to play central roles in defining industry concern and response to the threat of climate change (Jones et al. 2008).

26.6.8. Consumption: Current Food Insecurity

While the region is relatively food secure, there are significant disparities in food access among subpopulations, and this disparity is potentially associated with differential sensitivity to supply and price shocks associated with climate change. In the US, 14% of the population is now considered food insecure, the highest rate since 1995. Populations in lowest income brackets spend as much as 30% of income on food (Nord et al. 2010). Food insecurity in Canada and the US is associated with ethnic minorities and indigenous populations as well as the urban poor, and is often a function of economic access. While on average Canadian citizens are more food secure (Nord et al. 2008), populations such as the Inuit have very high documented levels of food insecurity (Ford and Berrang-Ford 2009). Mexico continues to report high levels of food insecurity, affecting both rural and urban areas, with the highest prevalence in the center and southern states among indigenous communities, where prevalence rates of 25-35% or even over 50%, are not uncommon. (Juarez and Gonzalez 2010). Evidence from the commodity price spikes of 2007-2008 indicate that the impacts of climate change on food prices will likely negatively affect these populations form whom climate impacts on food affordability is particularly critical, but more research is needed (Darton-Hill and Cogill 2010; Bloem et al. 2010).

26.6.9. Food Access and Climate Change

Rising oil prices and the increased cost of moving freight could be an increasing concern for the region's food systems. The movement of perishable commodities may also be affected by climate impacts on infrastructure due to sea level rise, more frequent flooding, heat waves and changes in the incidence of tropical storms (Curtis 2009). The port of New Orleans, for example, manages 64% and 67% of US corn and soybean exports and the majority of coffee imports into the US (Schnepf and Chite 2005). The experience of Hurricanes Rita and Katrina in New Orleans suggests that this port is resilient, however if the hurricanes had occurred at the peak of the export season a greater impact might have been recorded (Transportation Research Board 2008). Although impacts will vary from region to region in the Canadian Arctic, physical access to traditional hunting grounds in some communities is threatened by sea ice melt and permafrost loss (e.g., Krupnik and Jolly 2002) although improved access to fishing grounds may also emerge in some regions (e.g., Steward et al. 2007), as summarized in Ford and Pearce (2010) and Pearce et al. (2011).

26.6.10. Food Safety and Utilization

Food quality and safety and thus public health may also be affected by climate change (see section 26.3). As yet, there is little research on the potential for increased food borne illness risk in the region as a result of climate change, although some studies have found relationships between temperature and food borne illnesses (Schmidhuber and Tubiello 2007). For example, there is some evidence that warmer seas may contribute to increased risks to consumers of *ciguatera* (poisoning from shellfish) in tropical regions and a poleward expansion of the disease (Schmidhuber and Tubiello 2007). Several studies have found a positive relationship between increasing temperatures and food borne illnesses in the US or Canada (D'Souza et al. 2004; Kovats et al 2004; Fleury et al. 2006). More research is needed on this concern, particularly in Mexico where little research on climate and food safety has been undertaken.

Climate change will also likely affect cultural aspects of food utilization, such as the availability of preferred foods of cultural value and nutritional importance. In the Canadian Arctic, the social networks and practices associated with traditional food acquisition and use are threatened by climatic changes that inhibit harvesting practices or reduce the availability of hunted traditional foods (Ford et al. 2005; Pearce et al. 2011), with negative effects on nutrition for some Arctic communities (Wesche and Chan 2010). In Mexico local maize landraces often play important roles in local diets while enhancing the flexibility of communities to respond to agroecological and inter-annual climatic variations. Recent research has identified potential challenges to in situ conservation of local maize landraces under changing climate condition (Mercer and Perales 2010).

26.6.11. Regional Capacities to Address Changing Food Insecurity

Food security in the face of a changing climate will be affected by the capacities of public and private sector agencies to support at-risk populations. The increase in food insecurity in the US during the recent recession raises concerns that current safety nets may not be adequate to address unexpected outcomes from the synergies of climate change impacts on crops, rising oil prices and tightly integrated global markets. Over the last decade, the number and diversity of alternative markets and channels of food access (including farmers markets, community supported agriculture, community gardens and urban farms) have increased in the US, in part in response to rising levels of local food insecurity (Nord et al. 2010) as well as for health and sustainability motivations. In Mexico following NAFTA the importance of international and national supermarket chains have increased as sources of food in urban areas (Schwentesius and Gomez 2002; Reardon and Beregue 2002; Bils 2008), nevertheless markets of direct sale still persist even in large metropolitan cities. While these later avenues of food supply and trade are not necessarily less sensitive to climate change impacts, and to competition over water and land access, their presence may enhance the resilience of local economies and consumers to global price and supply shocks associated with climate change. The growth of Food Policy Councils in the United States, in which local governments collaborate with consumer and producer representatives, non-profits and local businesses to address local food system sustainability concerns (Harper et al. 2009), are promising in that they provide forums for communities to define strategies for coping with vulnerabilities and change in local food distribution and access. Further research is needed on the implications of diversity in supply chains in relation to changing climate conditions.

26.7. Rural or Resource-Dependent Communities

26.7.1. General Overview

17% of US population considered rural; Proportion similar in Canada. In Mexico the proportion of the population is much higher (23%). In general, per capita income is significantly lower than for urban residents in all three countries. 396 of the 460 U.S. counties classified as having low employment were rural (Whitener and Parker 2007). In rural Mexico, based on 2005 statistics, 47% of the population lived in poverty, with 18% of the population living in extreme poverty (Skoufias, Vinha and Conroy 2011 In U.S. and Canadian rural communities the residents are aging and, in many regions, experiencing a steady decline in population numbers as birth rates fall and younger residents migrate in search of education and employment opportunities (McLeman 2010).

Rural communities have limited services, especially health care and education. Rural residents tend to face higher financial and travel costs to access health care and pay a greater share of household income for health care than their urban counterparts (Jones et al. 2009). Emergency response systems are often less effective in rural areas because the population is dispersed and geographically isolated (Lal, Alavapalati and Mercer 2011). Another source of vulnerability: limited physical infrastructure needed in extreme event scenarios.

In most cases rural communities are economically dependent in some way on local ecosystems, and are therefore especially sensitive to changes in those systems This dependency is also associated with historic tendencies that promote overspecialization in agriculture or raw materials production, increasingly under the control of international centres of power, prevents diversified local economic development (Warriner 1988), enhancing vulnerability and limiting adaptive capacity.

Adaptation constraints are several, beginning with low social capital and limited economic resources. There are other concerns as well: According to Sander-Regier et al 2009, even for those communities motivated to engage in adaptation planning, climate scenarios that typically deal in average temperature and large geographical scales are not meaningful at the local level, where risks are experienced in deviations from norms and in locally specific interactions with climate. Extreme events are more pressing concerns than changes in long-term average conditions. In Mexico, the impacts may be severe. For example, Skoufias, Vinha and Conroy 2011 conducted a quantitative study in three regions estimating food and health-related expenditures under climate change scenarios, showing that as climate impacts income, expenditures in these areas can expect to decline, and concluding that climatic variability associated with climate change is likely to reduce the effectiveness of the current coping mechanisms further.

The remainder of this section will provide a brief overview of several community types. Many rural communities have mixed economies, but for ease of discussion we will focus on rural communities for which a single economic sector predominates, which are the most vulnerable. But first, we will focus on Aboriginal rural communities, because Aboriginals are among the most vulnerable groups of North Americans, and a large proportion live in rural communities. Agricultural communities will be discussed in the section on agriculture and food, and are not discussed here.

26.7.2. Indigenous Communities

General vulnerability characteristics: higher degree of reliance on local hunting and harvesting of food; among the poorest families in Canada and the U.S. (will add information on Mexico in future drafts.) [(and I presume Mexico but do not yet have any data)] and thus are [severely] lacking in resources for adaptation; many communities associated with significant infrastructure deficits. Many communities face dual impacts of climate change and industrial resource development (CIER 2007). The Centre for Indigenous Resources (2006) conducted an in-depth study of First Nations communities in Canada, in which interviewees observed changes in weather, water and ice conditions, and winter roads and access trails, described as being most profound in the last ten years. Multiple concerns were expressed, including reliability and safety of winter roads; decreased participation in sustenance activities; hindrance of community operations and economic development.

- For special consideration: High vulnerability among Aboriginal communities in the far North in Canada and Alaska. The most extreme warm years over the entire Canadian North have been recorded in the last decade, with the greatest temperature increases observed over the western Arctic (Prowse and Furgal 2009). Mean reductions of annually averaged Arctic sea ice area in 2080–2100 of between 22% and 33% are forecast (Zhang and Walsh 2006). Likely impacts will also include changes in the timing and duration of the spring melt season (Rigor et al. 2000), increased precipitation (Kattsov et al. 2007), later freeze-up and earlier break-up of river and lake ice (Walsh 2005); increased frequency of extreme weather and storm events (Kattsov and Kallen 2005). Many changes already observed by community members (Centre for Indigenous Resources 2007).

- Impacts already being felt:
  - Loss of permafrost and other infrastructure threats will affect all economic sectors, and adaptation will likely have costs (Prowse et al 2009). Zhang, Chen and Riseborough (2008) estimated that terrain currently underlain by permafrost in Canada would be reduced by 16.0–19.7% from the 1990s to the 2090s. Hazards such as coastal erosion, permafrost thaw, slope instability, and flooding, have already been damaging the built infrastructure, and threaten to constrain future community development, and changes in sea ice thickness and high winds are affecting the usability and safety of transportation networks (Ford, Bell and St- Hilaire-Gravel 2010). Risks to water quality and supply are immanent because the access, treatment and distribution of drinking water is generally dependent upon a stable platform of permafrost for pond or lake retention (Prowse and Furgal 2009). Many Aboriginal communities depend on cold weather and reliable ice for their social, cultural and economic survival (Centre for Indigenous Environmental Resources 2006).
  - Food staple species are threatened. (exs: caribou, ringed seals, polar bear, fish species). Two of the most important wildlife species to the Inuit are also the two most threatened by climate change: polar bears and ringed seals (Wenzel 2009). Polar bears provide important cash income, in the form of quota sales to sport hunters. Ringed seals are an important food source, making up approximately 54% of the edible biomass. Arctic char, another important food source, may lose 40% of its current range by 2020, and by 2050, their range may be reduced another 23% (Chu, Mandrak and Minns 2005).Other important species for Arctic communities include caribou; beluga whales, several varieties of trout and geese, seals, and musk-ox (Andrachuk and Pearce 2010). Andrachuk and Pearce (2010; see also Pearce et al. 2010) found that changes in seasonal patterns, sea ice, and weather variability have all affected the health and availability of important wildlife species and increased personal risks associated with hunting and travel.

- Vulnerability: A large proportion of Northern residents engage in subsistence lifestyles, with local ‘country foods’ making up a significant proportion of their diets (Andrachuk and Pearce 2010; GNWT 2008). Not only are food supplies at risk, but traditional food consumers are also at risk of infection by some zoonotic diseases projected to increase in the North, particularly if food is consumed raw or fermented as per traditional preparation techniques. Direct health impacts of climate extremes and natural disasters are most significant for communities and individuals living in more environmentally exposed locations (e.g., remote, low-lying coastal areas and isolated mountainous regions), and for elders and individuals with an already challenged health status

(Prowse and Furgal 2009). Youth and those without access to economic resources are also particularly vulnerable (Ford et al 2008).

- Prospects for Adaptation. According to Wenzel (2009), a warming Arctic is not an insurmountable threat; adaptation strategies can be applied. There are certain potential "replacement" species like narwhal, beluga whales and harp seal that will be less affected by climate change (Wenzel 2009). Adaptations to manage infrastructure risks include construction of buildings on piles, the use of non-pipe based water and sewage distribution, construction of shoreline protection, drainage diversion and control channels (Ford, Bell and St-Hilaire-Gravel 2010). Risks of using trail networks are moderated by traditional knowledge of trail conditions (ibid.). Key factors in adaptive capacity include diversity of local economies and extent of reliance on subsistence harvesting. Some northern Aboriginal communities, such as those studied by Ford et al (2007; 2008) in Nunavut, have exhibited high degrees of climate adaptability. In one case study (Ford et al. 2009), researchers found evidence of significant adaptive capacity in the form of social learning and local institutions adopting strategies to reduce infrastructure risks. Pearce et al. (2010) found that hunters cope with changes by taking extra precautions when travelling, shifting modes of transportation, travel routes and hunting areas, and switching species harvested, but wage-based employment constrains the schedule flexibility needed. Diets can also be supplemented with store bought foods, although they are too expensive for many, and considered less healthy and culturally acceptable (Pearce et al. 2010). Northern Aboriginal communities, as with Aboriginal communities throughout North America, face serious challenges to adaptive capacity, perhaps the most important being that "climate change is not necessarily a top priority for local leaders often already overcommitted to other concerns" (Sydneysmith et al 2010, p. 149). Key processes important to adaptive capacity have been diminished recently in many Aboriginal communities, including the erosion of traditional knowledge and skills, the weakening of social networks, and a reduction in harvesting flexibility (Ford et al. 2007). Ultimately, effective adaptation will require higher level government engagement (Centre for Indigenous Resources 2006).

26.7.3. Tourism-Based Communities

Tourism-based communities tend to be dominated by low-wage, service-based employment, and often small businesses. Those dependent on outdoor recreation are of interest here, as amenities are sensitive to climate change. Some areas, such as the mountain parks in Canada, may have opportunities in the form of longer travel seasons, but these [are] [insert: can be to some degree] countered by increased forest fire risk, potential loss of desired fishing species and megafauna, loss of glaciers, etc. (Scott, Jones and Konopek 2007). Winter sport-based communities on the other hand face a shorter season. Some ski operators, in both the mountain parks and in the northeast, have the option of using snow-making equipment, but the added expense, high water and energy requirements could be prohibitive (Scott, McBoyle and Minogue 2007; Scott et al. 2006). According to one modeling analysis, the majority of the Northeast U.S. ski resorts will no longer be viable by the end of this century under a higher emissions scenario (USGCRP 2009). According to Tufts {in Lipsig-Mumme et al 2010} Very little research has been done on tourism employment, limiting our ability to forecast changes due to climate change; however, adjustments will be inevitable as some opportunities shrink (e.g. skiing) and others emerge (e.g. longer golf season and other summer recreation). The impacts of disaster events can be very uneven. According to a study of the impacts of a forest fire in tourism-based Okanagan BC, the event caused total losses of 10-20% of seasonal revenues, although some businesses exp loss of 90% due to fire-damaged infrastructure (Hystad and Keller 2006).

Adaptation prospects: Tourism-based communities are often made up of several small businesses that lack the resources for effective emergency preparation. Hystad and Keller's study of the Okanagan fire noted above also identified a lack of emergency planning among small business owners, even in the years following the event (Hystad and Keller 2006; 2008). Based on their business survey, 39% of businesses over 50 employees have a disaster plan compared to 22% of those businesses under 5 employees (ibid.). Tourism Kelowna, the tourism marketing organization in the Kelowna region, did not have any disaster management strategies in place either (Hystad and Keller 2006). Few of those smaller businesses even developed disaster response plans after the fire (Hystad and Keller 2008).

Employment adjustment is a concern for communities facing long-term amenity changes. "Even short periods of adjustment require some support for workers and the current Employment Insurance system in Canada is simply not geared toward low wage service workers who qualify for lower benefits and are forced to quickly find new employment" (Tufts {in Lipsig-Mumme et al 2010}). Some adaptation technologies, such as snow-making, come at a high cost, especially given the likelihood for reduced revenues due to shorter season, and they require high volumes of water (Scott et al. 2006).

Coastal communities. Not all coastal communities are tourism-based, but many are, and thus will be dealt with here. These communities will face sea-level rise, as well as storm surges, wind and wave impact, and for northern communities, ice movement (Daigle 2006). Considering the extensive coastal property development in many such communities, the economic risks are significant. As well, as shown by Daigle (2006), in a study of coastal New Brunswick, large areas of coastal habitat and wildlife, which are sources of tourist attraction, will be influenced.

26.7.4. Forest-Based Communities

Holmes {in Lipsig-Mumme et al 2010}: Forestry makes up a small proportion of the Canadian workforce, but in close to 200 communities across Canada, more than 50 percent of workers are directly dependent on forest products for their livelihood. (Still need to get data for U.S. and Mexico). Over-dependence on the forest sector has been instrumental in contributing to the current predicament of the province's forest-dependent communities (Markey and Pierce 1999; Horne 2004; Markey et al. 2005; Natural Resources Canada 2009b).

Forecasted impacts: Loss of forest productivity from outbreaks of insects and diseases (Volney and Fleming 2000, Volney and Hirsch 2005); damage by extreme events, like wind (Peterson 2000), hail and ice storms (Hopkin *et al.* 2003), and thaw-freeze events (Auclair *et al.* 1996); increase in the extent, frequency and severity of drought and fire, especially in climatically dry regions such as the western Canadian interior (Hogg and Bernier). Drought-stressed forests are also likely to become more susceptible to insects and diseases (Volney and Hirsch 2005).

Increased fires have direct implications for the forest products industries, and also for municipal expenses. Ruth et al. (2007) predicted that the climate-change-induced warming will mean that the state of Washington will face fire suppression cost increases of over 50 percent by 2020 and over 100 percent by 2040.

McKenney et al (2007) analyze 130 N. American tree species, forecasting significant shifts in range. A shift in the species make-up of forests will also have significant impacts on forest industries. If the forests in the South and Northeast shift to oak and hickory species in lieu of softwoods, for example, the pulp/wood fiber industry could experience large losses (USGCRP 2009). The impacts in northern latitudes are more ambiguous. Johnston and Williamson (2005) evaluate anticipated impacts on productivity of white spruce, a species of high economic value in Canada, showing that under most future scenarios, stand productivity increases, but decreases under extreme drought. As well, projected increases in area burned will offset productivity increases. Climate change may also have a dampening effect on the prices of forest products in global markets due to higher growth rates and increased supply, particularly in developing countries (Sohngen and Sedjo 2005). Sohngen and Sedjo (2005) estimate average annual producers' surplus losses from climate change in the North American timber sector in the range of \$1.4 – \$2.1 billion per year over the next century.

[INSERT FIGURE 26-4 HERE
Figure 26-4: Title? Source: Hogg and Bernier, ____.]

Adaptation prospects: Seed planning zones, reforestation standards, and hydrologic and wildlife management guidelines are designed for the current climate regime, and there are no requirements for adaptation strategies in forest management plans, nor are there guidelines and sufficient experienced personnel to aid such activities (Spittlehouse 2008). One adaptation option is the "human-assisted migration" of tree species more tolerant to anticipated future conditions (e.g., ponderosa pine) through artificial regeneration (Hogg and Bernier). Emerging green industries may tempter negative impacts: Many forest product mills already have co-generation projects producing heat and electricity for use in the mill, and there are planned projects to build wood-fired electrical generating plants in BC and bio-refineries to produce bioethanol and synthetic biodiesel from wood in Québec (Holmes {in Lipsig-Mumme et al 2010}). Joseph and Krishnaswamy (2010) conducted a comparative study evaluating the relative success of f-b communities attempting to diversify their economies in BC, noting several constraints to doing so.

26.7.5. Synthesis

According to McKinnon and Webber (2005), the field of climate change impacts and adaptation has received less attention and funding resulting in significant knowledge gaps and lack of action. General understanding of rural community adaptive capacity: Local knowledge, action, participation, and local empowerment/control are important in determining community disaster response (Flint and Luloff 2005). Wilkinson (1991): social interaction at local level generates/perpetuates cooperation and common identity. Interactional capacity: "ability of residents to work together in a collective, community response to problems." Plays key role in effective mobilization of resources. Flint (2004), in a study of Alaskan community response to spruce bark beetle, showed that towns with high levels of community participation/involvement were more likely to be actively engaged in responses.
Communities are constantly being exposed to multiple stresses are also constantly adjusting; the ability to cope with and adapt to climate change depends on the pre-existing social and environmental conditions Brklacich and Woodrow (2007).

26.8. Insurance

Extreme weather emergencies are expected to increase in frequency and severity in the years ahead (Ashdown 2011). Insurance is a tool that can prefund the cost of rebuilding after disaster strikes, measure the adverse impact of extreme weather and other risks, and promote investments in damage-resilient buildings and infrastructure. Insurance is the business of managing risk, and in North America this includes many climate hazards.

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Box 26-3. Climate Change and Extreme Events in North America

The state of science on changes in extreme weather events, which will affect the insurance industry, and other sectors, is briefly reviewed here.

Extreme storms. Theory and climate model experiments suggest that a warmer atmosphere will result in increased precipitation intensity as the saturated vapor pressure of the atmosphere increases, potentially leading to increased flooding. However, the dynamics governing the response of individual extreme storms to elevated greenhouse forcing is less well understood. Severe thunderstorms in North America are presently associated with high values of convective available potential energy (CAPE) and vertical wind shear. Vertical wind shear over the mid-latitudes is expected to decrease in response to decreases in the pole-to-equator temperature gradient, although associated poleward shifts in the warm-season storm track could be expected increase occurrence of strong shear poleward of the areas of current peak occurrence. Conversely, increases in atmospheric temperature and humidity are expected to increase CAPE over the mid-latitudes of North America. The net impact of these opposing effects on extreme thunderstorm environment frequency remains unknown, although work to date suggests that increases in CAPE could overcome decreases in shear, leading to increased occurrence of severe thunderstorm environments. However, even if that outcome is robust, the response of individual storm dynamics – including those regulating tornado occurrence and severity – is not well understood.

Tropical cyclones. Enhanced greenhouse forcing could impact the occurrence and severity of tropical cyclones striking North America through a number of mechanisms related to ocean and atmosphere dynamics, including tropical sea surface temperatures, basin-scale sea surface temperature gradients, and vertical wind shear. Given the present correlations between tropical SSTs and tropical cyclone occurrence, the robust tropical warming projected to occur in response to enhanced greenhouse forcing could be expected to lead to increases in tropical cyclone occurrence. However, excessive vertical wind shear can inhibit hurricane development. While there is variation in results, climate model experiments suggest that the net effect of changes in sea surface temperatures and wind shear induced by elevated greenhouse forcing is to decrease the total occurrence of hurricanes but increase the occurrence of the most severe hurricanes.

Drought. Theory and climate model experiments also suggest that warming of the atmosphere and ocean will result in acceleration of the hydrologic cycle that would bring both increased precipitation intensity and more prolonged dry periods. However, understanding of the effects of this global-scale acceleration on the hydrologic regime of particular areas of North America varies. For instance, while drying of the southwestern U.S. and northern Mexico appears robust, the response of the more variable central North America is less certain.

Wildfire. Recent shifts to earlier timing of snowmelt runoff have been linked to increases in wildfires in western North America (see Section 26.4.2). The response of snowmelt-dominated runoff in the western United States to elevated greenhouse forcing is robust, with climate model simulations suggesting that doubling of atmospheric carbon dioxide concentrations can be expected to shift the timing of snowmelt runoff at least 1 month earlier in the year, increasing the length of time during which fires can start.

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Insurance is one of the largest industries in North America, with annual premium revenue in the United States, Canada and Mexico exceeding US$ 1.3 trillion (Swiss Re 2010). The property insurance industry is mature in the United States and Canada, operating for more than two hundred years, and providing products that are purchased by most homeowners and businesses. These markets are very competitive, with hundreds of insurers offering a variety of coverages. The insurance market is small but emerging in Mexico. Most homeowners and businesses in Mexico presently do not purchase insurance, particularly for severe weather risks. A small number of companies dominate the insurance market in Mexico (Insurance Information Institute 2010).

More than half a century ago companies that traditionally dealt with fire and theft insurance expanded their coverage to also provide protection against damage from many severe weather perils. Some large, European-based insurers and reinsurers began addressing climate change more than three decades ago, including contributions to the international discussions about emissions reduction. Insurance companies operating in North America have primarily focused their concerns about climate issues on measuring the impact of severe weather events and promoting loss prevention actions for property owners and governments. However, insurers in North America have largely been absent from the discussions about emissions reductions (Mills, Lecomte and Peara 2001; Brieger 2001).

The insurance industry in North America is actively working to identify and champion loss prevention for a broad range of perils including flood, freezing weather, hail, high winds, hurricane, lightning, tornado, water damage and wildfire. Most insurance companies in the United States, Canada, and to a lesser extent in Mexico, have programs to identify and communicate loss prevention information to policyholders. In the 1980s, insurers in the United States established the Insurance Institute for Property Loss Reduction to support industry efforts. The Institute eventually transformed into the Insurance Institute for Business and Home Safety based in Tampa. In the 1990s Canada's insurers created the Institute for Catastrophic Loss Reduction based at the University of Western Ontario to support industry research and outreach with respect to severe weather and earthquakes.

Data reported by insurance companies across North America show severe weather claims paid doubled every five to ten years over several decades (Nutter 1999). Severe weather insurance claims paid in the United States primarily include property damage from hurricanes, tornadoes and wildfire. Payments in Canada primarily include damage from basement flooding, winter storms and severe wind. Recent payments are trending higher and are many-fold greater than twenty or thirty years ago. Data provided by Property Claims Services, Insurance Information Institute, Swiss Re, Munich Re and others seek to measure severe weather payments made by insurance companies in the United States and Canada, and estimate losses not covered by insurance.

Private insurance coverage is largely similar for homeowners and businesses across the United States, Canada and Mexico. Property insurance policies were initially designed to cover the risk of loss from fire and theft, but evolved over the past century to add coverage for many severe weather perils within the basic policy, or, in some instances, as an optional additional endorsement. Overland flooding is perhaps the most common climate peril with special treatment (Sandink 2010). Flood insurance is available for businesses in the United States, Canada and Mexico, but private flood insurance is not available for homeowners in the United States or Canada. The federal government in the United States in 1968 established a public flood insurance program for homeowners. Most provincial governments in Canada have established disaster relief programs to provide limited financial support to homeowners that experience damage from flooding or other uninsured perils.

Considerable research has been conducted seeking to explain the large increase in insured and uninsured damage from severe weather events experienced over the past few decades. Some studies argue that the increase in damage reflects a significant expansion of the population living at risk and society's growing exposure to severe weather, but this research argues that change in the climate has not affected the reported losses (Pielke et al, 2001; Pielke et al, 2008). Other research argues that an increase in the frequency and severity of extreme weather explains part of the rise in property damage, and that this increase is due in part to climate change (CERES 2009; Dlugolecki 2008; Allianz/WWF 2006; Lloyds 2006). Research on the impact of climate change on disaster damage trends is continuing and may be important for assessing expectations about the future impact of climate extremes and the economics of options for adaptation. There is a consensus that there has been a large increase in severe weather damage and this trend will continue unless aggressive remedial actions are taken. Unresolved at this time is the role that climate change may have contributed to the reported increase in damage, and the potential contribution of climate change to the expected future losses.

The focus of the insurance industry on championing adaptation and loss prevention is consistent with the industry's history (Kovacs 2009). Over many decades insurance companies have promoted road safety, fire prevention and crime prevention. As extreme weather losses have become a larger share of the insurance industry's paid claims, it is natural that the industry has also become more active in promoting adaptation to climate extremes. This includes promoting stronger building codes as a means of increasing the resilience of new homes to severe wind and water damage, and championing wildfire safety measures for homes located in the urban/wildland interface (Kelly 2010; Kopp 2008; Kopp 2006; Bartlett 2006; Kovacs 2005).

Beyond championing stronger building codes and code enforcement as a means of making new structures more resilient to severe weather, insurers are also actively supporting communications to policyholders about adaptation of existing buildings. These activities address a broad range of perils including fire and theft and many climate risks, including the risk of damage from water, severe wind, lightning, wildfire and winter storms. These public outreach efforts have been conducted by individual insurance companies, at the industry level, and through partnerships with government agencies and not-for-profit agencies like the Red Cross. These efforts employ a range of tools including information brochures mailed to policyholders, web-based information, workshops, and media events. Collaboration between the insurance industry and public policy agencies includes international, national, state and local initiatives.

Insurance is a business, and for private insurance coverage for extremes to be sustainable it is important to address the risk of adverse selection. Property owners may have greater information than insurance companies about the risk of damage to a specific property, so high risk property owners have a greater interest in securing insurance, other factors held constant, than lower risk property owners, establishing a potential for adverse selection. Bundling coverage so all or most property owners at risk share in the costs and benefits of coverage is a mechanism of managing adverse selection, and this has been most effective when done by insurance companies in partnership with governments (Paklina 2003). In particular, the availability and effectiveness of private insurance is enhanced when governments make a conscious decision to not provide compensation to disaster victims. The affordability of insurance is managed when a large number of companies compete to serve the market, and in the US market for homeowners insurance this is reinforced by public regulation of pricing, terms and conditions.

Considerable change has taken place within the insurance industry to adapt practices to address the growing damage claims resulting from severe weather. Traditionally property insurance pricing and coverage has been based on an assessment of recent loss experience. It has been evident for more than a decade in the United States and Canada that recent history is not sufficient to plan for potential future severe weather losses. Insurers are beginning to use climate models designed to support decision-making by insurance companies. Initially the focus was on risks to capital, and supporting decisions about the purchase of reinsurance and other mechanisms designed to reduce the risk of an extreme weather event overwhelming the financial capacity of an insurance company. Recently climate models have been designed to support decision-making about pricing and other underwriting issues. These models continue to evolve, and support traditional historic or actuarial analysis (Lloyd's 2006).

In 2001 the IPCC WGII third assessment observed that increasing damage resulting from extreme weather events were expected to increase future damage claims paid by insurance companies, and that such events could also increase the risk of insurance companies failing. The evidence confirms that insurance damage claims paid have since increased significantly, perhaps even faster than anticipated in the literature available at that time. However, the number of insurance companies that have failed due to extreme weather has not been rising. Indeed, insurance companies failures due to severe weather peaked in 1992. Insurance companies have adapted their practices through the use of models, greater attention to price adequacy, the introduction of caps and limits on some coverage and generally by devoting much more attention to the management of climate risks. Higher damage claims have not resulted in an increased risk of insolvency (Leadbetter *et al* 2007).

A particular concern has been the growing risk that severe weather events can bring extensive damage, and constrain the capacity of private insurance market. A number of countries in Europe (France, Spain, Norway and Switzerland) have accepted the view that governments are ultimately responsible when large-scale disasters strike, and formal programs are in place setting out public mechanisms for responding to very large events. Some markets in North America (Florida and Texas) have established risk pools to address extraordinary events for specific perils like hurricanes and tornadoes, while policymakers are discussing the potential of establishing a national program to backstop the insurance industry should an extraordinary event strike. Similar discussions have not yet taken place in Canada.

Most insurance contracts in North America cover a period of 12 months, providing the industry with flexibility to manage new information about risks, including changes in the risk of severe weather. Adjustment in insurance practices often takes place following a delay of a year or two to understand and address emerging information. This introduces additional risk into the system when ongoing change is taking place, but the risk for insurance companies is less than that experienced by industries required to make longer-term decisions because insurance companies have the option of adapting their practices (Mills 2009).

Mexico presents a special opportunity within the North American insurance market. Countries with a rapidly growing middle class and affluent populations typically experience a significant increase in the use of insurance (Swiss Re 2010). The property insurance market is small but growing in Mexico, and is presently the second largest market in Latin America after Brazil (Insurance Information Institute 2010). Significant further growth is expected over the next few decades. Private insurance coverage for homes and industry are largely similar in design in Mexico to that presently in place in the United States and Canada, and this includes coverage for most severe weather perils in the basic policy. The major difference in the current Mexican property insurance market from that elsewhere in North America is the concentration of business within a small number of dominant companies. Over time consumers in Mexico will benefit if there is increased competition in the market as a means to ensure affordability of coverage and innovation in coverages provided.

There is also a growing literature identifying options for introducing and expanding the role of insurance in markets, like Mexico. Proposals from the Alliance of Small Island States, the Munich Climate Insurance Initiative, and others have focused on opportunities to promote microinsurance (insurance for the uninsured) and insurance for governments designed at a regional scale (Warner et al 2009; Bals 2006). The Inter-American Development Bank provided a US$ 26 million loan in 2010 to the Federacion Interamericana de Expresas de Seuros (FIDES) to promote the microinsurance market in Latin America, with a special focus on expansion in Mexico. And the Caribbean Catastrophe Insurance Facility has been identified as a potential model to bring insurance against severe weather risks to Mexico and a number of other countries.

Governments in North America sometimes promote private insurance. Public agencies also maintain regulatory systems to monitor to solvency of insurance companies to ensure consumer confidence that insurance companies have the financial capacity to pay claims. Governments are also responsible for providing essential information and services required to operate insurance companies, including reliable information of historic weather events, land use planning and enforcement of building codes.

There is a growing literature over the past decade suggesting that financial instruments may emerge as an alternative to traditional insurance and reinsurance for the management of severe weather risks (Michael-Kerjan, Erwann and Frederic Morlaye 2008; Kunreuther, Howard and Erwann Michel-Kerjan 2007; Csiszar, E. 2007; Barrieu, P. and H. Louberge 2007; Barrieu, P. N. El Karoui 2002). This includes alternative risk transfer mechanisms, catastrophe bonds, and insurance-linked securities. These instruments have been in place for more than a decade but represent a small share of the insurance market, in part because they remain expensive in relation to traditional insurance and reinsurance products. Nevertheless, these tools are now established as viable mechanisms that can be used to manage severe weather risks.

Finally, in some markets in the United States and Canada insurance pricing and availability provides incentives to encourage property owners to invest in adaptation. For example, water damage during severe rainfall events has recently emerged as the largest claims cost for most insurance companies in Canada, and some insurance companies will only continue to provide coverage following a loss event if property owners install backwater valves and/or sump pumps. Some other insurers offer a price discount for policyholders with these protective adaptations (Sandink 2011). Similarly in Florida, the state regulator has worked with the insurance industry to establish a series of price discounts available to property owners that have installed specific loss prevention measures (Mills 2009). The concept of linking risk and pricing is a natural element in the provision of insurance, with the potential of providing long-term incentives for property owners to invest in adaptation to climate extremes.

26.9. Energy

In North America, the energy sector has generally been viewed as a mitigation issue for climate change science and policy, but in fact it is also a sector whose future will be affected by climate change. This section will briefly summarize the major risk management concerns by country and provide examples of several notable issues.

In general, the energy sector is distinctive in at least three ways, apart from its central importance in climate change mitigation and climate policy: (1) like food and water, energy services are viewed by society as an entitlement, not as a commodity; regardless of driving forces such as climate change, institutions are expected to assure the provision of those services abundantly, reliably, and affordably; (2) its infrastructures tend to be very large, associated with decisions by large institutions at large investment levels, often with significant capacities for risk management; and (3) it is connected with every other sector, in the sense that impacts on the energy sector affect other sectors as well, through such effects as energy prices and energy supply reliability, and impacts on other sectors often affect the energy sector as well, especially through effects on energy demand (for instance, energy requirements for water pumping).

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Box 26-4. Changes in Extreme Hot and Cold Temperatures

Climate model simulations suggest that increased greenhouse forcing will lead to increases in the occurrence of hot extremes throughout North America. These increases result in part from mean warming shifting the temperature distribution, thereby increasing the occurrence of temperatures above a particular critical threshold. In some areas, these increases also result from a change in the temperature distribution, with spatial variations in the magnitude of intensification of extreme hot occurrence being influenced by changes in the large-scale atmospheric circulation and by fine-scale surface-atmosphere interactions. A number of climate model simulations also suggest that increased greenhouse forcing will lead to decreases in the occurrence of cold extremes in the mid- and high- latitudes where extreme cold presently amplifies energy demand, with some simulations suggesting that the increase in extreme cold temperatures could be greater than the increase in extreme hot temperatures. The effect of mean warming shifting the temperature distribution towards decreased occurrence of cold extremes is robust. However, the effect of changes in the large-scale atmosphere and ocean circulation is less robust, as the atmospheric conditions that create extreme cold events exhibit substantial inter-annual variability and are strongly coupled to the state of the ocean. Further, snow cover exerts an important influence on the surface energy budget, and although local decreases in snow cover associated with winter warming have been shown to amplify greenhouse-induced decreases in the occurrence of extreme cold events, potential feedbacks between changes in atmospheric circulation and snow cover are not completely understood.

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26.9.1. Canada

Major impact issues include: significant increase in electricity requirements for cooling; adverse effects on hydroelectric potential in both western and eastern Canada; combining demand and supply impacts, increased number of blackout/brownout events (Natural Resources Canada, 2007); Arctic thawing/melting affecting prospects for energy production and transportation; effects of climate policy on Alberta oil sand resource development….

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Box 26-5. Alberta Oil Sands and Climate Policy

Athabasca oilsands is a major provider of US oil, and economic engine for Alberta. Oilsands production will be impacted by climate change directly in the form of infrastructure risks and water demands, and indirectly by anticipated climate change mitigation strategies that impose a tax or cap on carbon emissions.

Infrastructure will be threatened by extreme events, and also by melting permafrost, which will negatively impact both road and pipeline infrastructure. In one study conducted in NW Canada (Bonnaventure and Lewkowicz 2011)under warming scenarios, permafrost probabilities progressively declined and zonal boundaries rose in elevation. A mean annual air temperature change of +5ºC scenario, caused two of the study areas to become permafrost-free. The Arctic Climate Impact Assessment (ACIA) notes susceptibility of transportation infrastructure in the Canadian North, which will affect oilsands production as well as oil and gas production in the far North: melting ice and weakening ground subsistence pose risks to the seasonal availability and safety of ice roads, and the structural integrity of overland roads, bridges, pipelines, and airstrips (Instanes et al. 2005).

Oilsands production is water intensive, requiring between 2-5 barrels of water per barrel of oil produced. Only about 10% of the water used is returned to the river since the water becomes heavily polluted in the process (Bruce 2006). Water is drawn from the Athabasca River. The annual average flow (1961-2000) of the Athabasca River near production sites is 630 m3/sec, but the winter low flow averaged 169 m3/sec. In Schindler and Donahue (2006), summer flow at Fort McMurray declined 19.8% from 1958-2003, but 33.3% (significant at 5% level) since 1970. If one assumes a continuation of the recent trends in future decades, minimum flows by 2050 could be as low as 37m3/sec. Withdrawals for oil sands development have been projected to reach as much as 19m3/sec. with planned and projected developments. Minimum winter flows in recent years have dropped to as low as 75m3/sec (2001-2002) (Bruce 2006)

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Box 26-6. Hydroelectric Power in Great Lakes/St. Lawrence Region

Hydroelectric power production in the St Lawrence/Great Lakes region could also be affected by climate change. According to Tin (2006), based on results from six climate change scenarios (HadCM2, CGCM1, HadCM3, CGCM2) and IPCC emission scenarios (IS92a, SRES), both lake levels and outflow could decrease under a 2°C global warming. Lake outflows could reduce by 5% to 26%, and a decrease in lake levels of 0.08 m to 1.18 m is projected. Findings by Minville et al. (2009) are not as pessimistic, finding that annual mean hydropower would decrease by 1.8% b/w 2010–2039 and then increase by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively. But overall , reservoir reliability would decrease and vulnerability increase.

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26.9.2. Mexico

The National Energy Balance reports energy production and use in 2008 (SENER 2010). It also shows that population and economic growth in Mexico is expected to grow in the near future and will add stress on the energy sector. Additionally, climate change may affect the energy sector.

On the demand side, climate change increases the demand for electricity for cooling. Energy demand will also likely increase in the agricultural sector and as precipitation is projected to decrease in parts of Mexico. Farmers that can afford it will likely use more irrigation that in turn will use energy for pumping purposes. Municipal water authorities will also likely rely more on bringing water from far away as their surface and groundwater sources are increasingly polluted (due to climate change among other factors) and depleted (because of lower recharge rates due to less run-off due to drought –and overuse-), and require more energy to do so.

On the supply side, the energy system will need to be revamped, as a consequence of climate change, to meet the government goals stated in the Special Program on Climate Change (Programa Especial de CambioClimático, PECC). This could imply relying more on renewable energy, mainly on hydropower that in itself may be limited by increasing water scarcity and extreme weather events. The latter have occurred in Tabasco and in the border state of Tamaulipas in recent years, where dams have been overflowed due to flashfloods and hurricanes.

Extreme events in Mexico are likely to have impacts on both demand and supply of energy. Hurricanes and flashfloods can disrupt energy production. On the other hand, more energy demand can be needed to restore damaged property and facilities, including generating capacity. (see discussion of tropical cyclones in insurance.)

Energy and industry-related production relies heavily on increasingly scarce water supplies for cooling purposes. This may increase the costs and/or technical difficulties of cooling processes. A significant amount of oil is being extracted from the sea. An increase in sea level may increase the costs of extraction or even affect feasibility of doing so. Pipelines through which oil and fossil fuels are distributed throughout Mexico may be affected by land subsidence, causing pipelines to break or leak.

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Box 26-7. Hydropower in Mexico: Feasibility under Extreme Weather Events

Major impact issues may include: increased demands for electricity for cooling, combining higher temperatures with development progress; water shortages where energy facilities are water-consuming; SLR plus storms on coastal energy facilities; possible effects on renewable energy prospects; climate policy effects on fossil energy development and use, along with revenues (natural gas markets may benefit, at least for several decades, while oil markets are depressed…).

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26.9.3. United States

Effects of climate change on energy production and use in the United States are characterized in a 2008 report by the U.S. Climate Change Science Program ( ) and in a 2009 report by the U.S. Global Change Research Program ( ). Aside from effects of climate warming in energy use in buildings, many of the effects have not been extensively studied, and most of the effects differ according to region of the U.S. But at a national scale, significant effects are expected to include increases in electricity requirements for cooling and reductions in energy requirements for heating, adding up to significant increases in electricity use and higher peak demand in most regions; effects of precipitation changes on hydropower potentials, chronically or seasonally; effects of severe storm intensity and sea-level rise on energy facilities in vulnerable coastal regions; and effects of climate policy on energy technology choices and possibly energy prices.

Other impacts are likely as well, including effects on energy production of rising temperatures (which reduce thermal power plant efficiencies) and limited water supplies in many regions (which can affect power plant cooling) and effects on renewable energy sources other than hydropower. For example changing cloud cover affects solar energy resources, changes in winds affect wind power potentials, and temperature change and water availability can affect biomass production (for instance, water requirements for biofuel production).

The overall scale of the U.S. energy economy is very large indeed, and the energy industry has both financial and managerial resources to cope with climate change effects ( ), but climate change impacts are likely to appear at regional and local scales, especially related to extreme weather events, water scarcity, and effects of increased cooling demands on especially vulnerable places and populations.

Regionally, major concerns include effects of increased cooling demands and water scarcity in the west; effects of extreme weather events, sea-level rise, and seasonal droughts in the southeast; effects of increased cooling demands in the northern regions; effects of warming on energy production and transportation in Alaska; and effects of climate policy on regions whose economies are closely tied to fossil energy production and conversion.

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Box 26-8. Energy-Water Nexus in the US

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26.10. Transboundary Stresses

Adaptation to climate change issues that are transboundary is complicated by the need to require actions by local, regional, NGO, and national organizations that do not reside in the same nation. Thus the adaptive capacity of these organizations will be affected by several factors (e.g., mismatches between climate and hydrological processes and policy making time frames and spatial levels of administrative action). In this section, we will address this issue in the context of two stressors; water management and vector borne diseases.

26.10.1. Water Management

This section will start with a short presentation of the literature on transboundary waters and climate change in North America (i.e., mainly just citations). It will then assess in more detail the literature on a case study that illustrates the complications to adaptive capacity of a transboundary climate change-induced water resources impact. The proposed case study is the Red River between Canada and the USA. The Red River’s flows are highly variable on an annual and seasonal basis, and demand for water in the basin could increase in future for a host of reasons, including changes in economic development, population growth and climate change. Flows in the basin are not currently apportioned between the two countries. Governance of the water resources of this critical shared basin, including decision making regarding apportionment of flows, should address adaptation to anticipated climate change. A multi-level approach to governance in the basin is required because responsibility and authority are shared by the national governments, state/provincial governments, and a host of local and non-government actors.

Vector-borne diseases

As in the case of water resources, this section will start with a short presentation of the literature on transboundary vector borne diseases and climate change in North America (i.e., mainly just citations). It will then assess in more detail the literature on a case study that illustrates the complications to adaptive capacity of a transboundary climate change-induced vector borne disease problem. The proposed case study is the dengue fever in the border region of the US and Mexico. It was chosen because it illustrates the complex nature of VBD surveillance and control in border regions, as well as the multifaceted influences on dengue prevalence, including climate, surveillance, vector control programs and others.

26.10.2. Distribution of Risks

The impacts of climate change, and the capacity to adapt, are not equal geographically or demographically. The particular vulnerability of groups who are exposed to the impacts of climate change by virtue of their geography is fairly readily identified. In this realm the most pertinent indicator other than type of impact is population density. The geographic distribution of climate change risks provides a demarcation of certain populations at risk. In North America, this includes populations living in coastal areas. One recent GIS-based study identified 19 million people in the coterminous United States who lived within one kilometer of the coast, and another 11.6 million who live below three-meter elevation (including 6.3 million in both categories), with Florida and Louisiana having the largest proportion of these groups (Lam et al. 2009).

While sea-level rise describes a long-term average climate impact, other impacts are far more acute, such as catastrophic weather events. There are a handful of studies that focus on the geographic distribution of extreme event risk in North America. Changon (2010) identifies the location of weather catastrophes across the United States during the 1949-2008 period. The Southeast of the country was shown to have the highest level of occurrences and financial losses, especially since 1990. Other types of exposure are not necessarily geographically defined, such as food price increases resulting from climate-related crop failures, or the probable costs of anticipated climate change mitigation policies, which will have the greatest effect on those with limited ability to absorb increased living expenses. Ahmed et al. (2009) link climate volatility to food price increases, which in turn threaten the wellbeing of the poor, particularly urban, wage-labor dependent households.

Another geographically expressed source of exposure of particular relevance to North America is water availability and quality, which is expressed both as a long-term average change (in evapotranspiration, e.g.), and as an acute event, in the form of drought. In combination, such impacts can send those areas already facing water limitations below an acceptable threshold of water availability to support current human settlements and/or current economic activities. The vulnerability of watersheds already under stress, such as those in the West and Southwest of the US, has been highlighted, but watersheds in the south are also vulnerable, not to aridity but to flooding, and associated water quality concerns (Hurd et al. 1999).

Vulnerability is much more than exposure, however, and includes the multiple social variables. The multiplicity of social vulnerability renders the ready identification of vulnerable groups difficult, but a number of research frameworks have emerged in an attempt to do so. Among the most often cited is the Social Vulnerability Index developed by Cutter (Cutter et al. 2003). Cutter and Finch (2008) use Cutter's Social Vulnerability Index to characterize U.S. Counties, and their shifts in vulnerability over time (1960-2010).

Identifying social dimensions that are associated with vulnerability is one thing, but assigning relative importance to each is empirically more challenging. That said, among those studies that have attempted just that, economic status, and the pool of material resources to which that status pertains, appears to be especially pertinent (Cutter and Finch 2008; others). Recent studies have highlighted the indirect means by which socio-economic status translates into vulnerability. For example, Posey (2009) evaluates the relationship between socio-economic data and the level of municipal government participation in flood management programs, showing a significant negative relationship between the aggregate socio-economic status of residents, and municipal government involvement in flood management. Interestingly, the study did not find the size of city budget to be relevant to level of flood management.

Beyond the availability of economic resources, other social dimensions that influence sensitivity and response capacity to the impacts of climate change, include factors that exacerbate the impacts, such as immune deficiencies, or the state of the built environment. Other factors inhibit emergency response, such as immobility; and still others characterize the level of resources available for extreme event recovery, or adaptation to irreversible changes in social conditions (e.g. occupational structure), including, for example, property insurance, wealth, and access to social support networks, which can vary according to education, income, race, gender, length of residency, mother tongue, and so on. In the Cutter and Finch (2008) study, New York was found to be the most vulnerable category for all three decades, a finding attributed primarily not to the prevalence of poverty, but to the built environment. Extreme population growth or depopulation were both identified in that study as a source of increasing vulnerability over time.

A smaller handful of studies move beyond generalized models of vulnerability to focus on particular types of exposure. Clark et al (1998), for example, map the overlap of social and physical vulnerability for a flood-prone community, Revere, Massachusetts, finding that types of vulnerability can vary greatly even in a single community, and hazard response planning would be most effective if such dimensions were accounted for. A fair bit of research on heat stress in urban settings has been undertaken, with residents in inner cities in general, and those located in the Northeast and Pacific Coast in particular, as highly susceptible to heat stress (Reid et al 2009). Bell et al (2008) conducted a three-city comparative study including Mexico City using historical data for the 1998-2002 period, indicating increased mortality risk among elderly, but differences in sex and education level were not notable. Reid et al. (2009) also highlight age as an important risk factor for heat events, as well as prevalence of air conditioning, amount of green space, education, poverty and race.

Regional disparities across the three North American countries are significant as well, with Mexico being characterized by much higher rates of poverty, and reduced adaptive capacity, in comparison to Canada and the United States. Eakin and Bojorquez-Tapia (2008) classified 55% of households in a farming community in Mexico as highly vulnerable (See also Luers et al. 2003).

26.10.3. Multiple Stresses

This section discusses how different impacts and stresses from climate change can affect particular regions or types of locations. Stresses can interact across North America, for example sea level rise and permafrost melting affecting Arctic communities. We address three locations or types of communities that are likely to face multiple stresses from climate change: the Gulf of Mexico, mountain communities, and Mexico City.

26.10.3.1. Gulf of Mexico

The region bordering the Gulf of Mexico in the southeastern United States and eastern Mexico will mostly likely be vulnerable to interacting stresses from climate change. Interactions between sea-level rise and tropical cyclones pose severe risk to coastal communities, infrastructure, and ecosystems (Field et al. 2007). The additive effect of rising sea levels and increased hurricane intensity, especially hurricane storm surges, poses risks to coastal infrastructure, as many buildings were not designed to withstand the intensity of projected storm surges (US GCRP 2009). These joint stresses will also likely greatly increase coastal erosion and flooding, with some low-lying areas and communities inundated more often or even permanently as sea levels rise (Kunkel et al. 2008; US GCRP 2009). In addition, these stresses will likely lead to increased erosion of barrier islands, coastal forests and wetlands, and drive increases in salinity in estuaries, coastal wetlands, and tidal rivers (US GCRP 2009; Anthony et al. 2009). The impacts of Hurricanes Katrina and Rita, which resulted in a loss of over 1,800 lives and 217 square kilometers of coastal ecosystems, illustrate the vulnerability of communities in this region to these interacting stresses (Barras et al 2006; Nicholls et al. 2007).

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Box 26-9. Changes in Tropical Cyclones

Enhanced greenhouse forcing could impact the occurrence and severity of tropical cyclones striking North America through a number of mechanisms related to ocean and atmosphere dynamics, including tropical sea surface temperatures, basin-scale sea surface temperature gradients, and vertical wind shear. Given the present correlations between tropical SSTs and tropical cyclone occurrence, the robust tropical warming projected to occur in response to enhanced greenhouse forcing could be expected to lead to increases in tropical cyclone occurrence. However, excessive vertical wind shear can inhibit hurricane development. While there is variation in results, climate model experiments suggest that the net effect of changes in sea surface temperatures and wind shear induced by elevated greenhouse forcing is to decrease

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Increases in the frequency, intensity, or duration of droughts, which are projected for the Caribbean region, will alter soil moisture, groundwater recharge, and run-off regimes in this region (Bates et al. 2008). These changes in water availability will be accompanied by increased evapotranspiration demands from higher temperatures, and the net drying effect is expected to outweigh any regional changes in precipitation (US GCRP 2009). Droughts in this region can tax regional water resources, stress terrestrial ecosystems, lead to salt water intrusion into aquifers, increase oceanic hypoxic zones, and affect aquatic ecosystems such as estuaries, which are greatly influenced by water influx for turnover and salinity (Mulholland et al. 1997; Scavia et al. 2002; Bates et al. 2008).

Climate stresses will occur in the context of other anthropogenic changes in the region, including continued coastal development, loss of wetlands to subsidence and habitat destruction, rising wetland and estuary salinity, fishing pressure, and eutrophication and hypoxic zones, and coastal development (Mulholland et al. 1997; Turner 2000; Harley et al. 2006). In some cases, climate stresses will exacerbate these ongoing changes. For instance, the compound effects of sea-level rise and tropical cyclones will likely accelerate the rate of wetland loss (Harley et al. 2006). Urban development along the Mexican coastline has impacted coastal ecosystems, including those such as mangrove forests that increase resilience to climate stresses, which leaves this region highly vulnerable to sea-level rise and storm impacts (Yanez-Arancibia 2009).

26.10.3.2. Mountain Communities

Mountain communities in the United States and Canada, and Mexico will most likely face a multiplicity of climate change impacts. Section 26.4.2 describes outbreaks of fire and pests. In western regions, these impacts have already been observed in the last several decades (e.g., Kurz et al. 2008; Westerling et al, 2006, US GCRP 2009), though disturbance will also affect eastern forests (Dale 2001). These disturbances include pests and pathogens, windstorms, hurricanes, and ice storms. Eastern forests are vulnerable to gypsy moth and Woolly Adelgid (SAP 4.3). As noted elsewhere in this chapter, fire frequency across the mountain west has increased, sometimes with severe consequences for mountain communities.

The sensitivity of communities to ecosystem impacts can vary depending on how closely tied communities are to specific ecosystem services (Breshears et al. 2011). For example, sudden die-off of piñon pines in New Mexico adversely affected commercial services derived from use of piñon nuts and reduced amenities for homeowners living near the forest. Reduction in the forest could also reduce risk of spread of hantavirus, though hantavirus risk has been found to increase in another forest die-off event of trembling Aspen in the same region (Lehmer et al. 2011).

Mountain snowpack is already decreasing across many mountain areas in the western United States (Mote et al. 2005), eastern United States (Hayhoe et al. 2007), and Canada (Mote et al. 2006). The ski industry, an important source of income in many mountain communities, will likely be constricted over the 21st century as temperatures continue to warm. While winter precipitation is projected to increase in many northern areas, the length of the ski season will be reduced (Scott et al. 2003; Scott et al. 2007; Lazar and Williams 2008). For example, ski season length is expected to decrease 5-39% in Ontario and Quebec by the 2050s (Scott et al. 2003; Scott et al. 2007). While adaptation through snow making could help compensate for declines in snow duration, and is considered in these studies, it would put substantial economic costs on ski areas (Scott 2005).

Summer drought constitutes a potentially significant issue in many mountain communities. Earlier snowmelt and reduced summer precipitation are expected to lead to decreased runoff and soil moisture in the summer. In regions currently ignition-source limited (as opposed to fuel-limited), this will contribute to more fires and make forests more vulnerable to pest infestations (US GCRP 2009). Severe drought has been linked to several widespread forest die-offs in the western United States (Breshears et al. 2005; Worrall et al. 2010). Droughts in this region are expected to be more frequent and severe, potentially leading to "Dust-Bowl" conditions within a few decades (Seager et al. 2007).

Changes in winter precipitation, run-off timing, and summer precipitation all hold potential to stress water resources in mountain communities (Barnett et al. 2005). For example, the effects of anthropogenic climate change have already been documented in water resources in the western United States (Barnett et al. 2007) and a key storage reservoir, Lake Meade, may lose live water storage within a decade (Barnett and Pierce 2008).

26.10.3.3. Mexico City

[To be drafted. This section will cover multiple stresses on Mexico City, including alternation of droughts and floods, water scarcity, air pollution, and disease.]

26.11. Social Distribution of Risks

[to be developed]

26.12. Multiple Stresses

[to be developed]

26.13. Irreversible Changes

Growing scientific evidence warns that global warming will have a lasting and potentially irreversible impact on climate and weather patterns (Parry et al 2007). In turn, this will affect ecosystems, settlement patterns and economic activity. The risk of irreversible climate change is a common concern raised across much of the impacts and adaptation research for North America.

26.13.1. Change in the Climate

Some changes in the climate are possible but highly uncertain, such as ice sheet collapse and change in global ocean circulation patterns (Hansen et al 2007). Other changes have been identified with greater confidence and include more intense weather extremes, sea-level rise and coastal flooding (Trenberth et al 2007). In particular, there is growing evidence that changes in the climate that take place due to carbon dioxide emissions are largely irreversible long after emissions stop. In particular, atmospheric temperatures will not drop significantly for at least 1000 years following the cessation of emissions (Solomon et al 2009). For regions of North America this will lead to dry-season rainfall reductions comparable to the "dust bowl" era; increased intensity of hurricanes; more frequent and severe rainfall events and flooding; inexorable sea level rise; permafrost melt; loss of glaciers and snowpack; and Arctic sea ice retreat (Solomon et al 2009).

26.13.2. Extinction

If climate conditions change so a species cannot reproduce locally then it will be doomed for extinction with the current generation (Malanson 2008). Extinction is an extreme example of irreversible change.

Acceleration in extinction of species has been recorded around the globe primarily due to habitat fragmentation, resource exploitation and climate change (Jackson and Sax 2009). In North America this includes the recent extinction of mammals (Columbia Basin Pygmy Rabbit and Vancouver Island Wolverine); birds (Bachman's Warbler); fish (Hadley Lake Sickleback and Maryland Darter); and plants (Pearson's Hawthorne).

The division of habitat into smaller contiguous pieces isolated by areas of non-habitat is seen as the leading cause of species extinction and endangerment (Jackson and Sax 2009). There has been some analysis of trade-offs between the available area for habitat and overall habitat quality, through investments in species-friendly farming (Green et al 2005).

Biodiversity research has lead to expressions, like "extinction debt", to describe the deterministic loss of species, in order of their competitive ability, following habitat loss and fragmentation (Malanson 2008). Forcing events affecting species diversity include changes in the quality, size, density and connectivity of suitable habitat patches. It may take many generations before a forcing event results in extinction (Jackson and Sax 2009).

26.13.3. Invasive Species

Species migration brings new species into an area, initially increasing diversity, but soon adding new pressures on ecosystems. Thousands of invasive species have been identified across North America. This includes mammals, birds, fish and plants. New species disrupt existing systems and can have a significant adverse impact on vulnerable species.

Immigration of species can be set in motion by a forcing event, like climate change, that drives changes in the quality, size, density and connectivity of suitable habitat patches. Once initiated, patterns and rates of immigration and extinction will determine changes in biodiversity. Equilibrium is rarely achieved quickly. The concept of immigration credit involves an assessment of the number of species that are committed to eventual immigration because of a suitable environment and opportunity. Equilibrium is reestablished after a forcing event once all extinction debts and immigration credits are realized (Jackson and Sax 2009).

It might be difficult to distinguish between recent immigration and extinctions that are due to environmental forcing that occurred recently or at some distant time in the past. The threat of underestimating or misunderstanding cumulative and complex climate impacts increases the difficulty of determining appropriate conservation policy actions.

26.13.4. Assisted Colonization

Assisted colonization is an example of conservation strategy that has been proposed to mitigate the potential adverse impacts of climate change on biodiversity (McLachlan, Hellman and Schwartz 2007). A species at risk can be transported to a new location that is predicted to be favorable for persistence under future climate and land use scenarios.

This strategy, however, has become the subject of controversy in the conservation community. Concerns have been raised about the manipulative nature of this intervention, and the potential that relocation will inappropriately disrupt native species (Scott, Terwilliger and Peterson 2011). While there is considerable uncertainty about the approach, assisted colonization appears most applicable for species with small populations and limited adaptive potential (Ozinga 2009).

Scott, Terwiller and Peterson propose that assisted colonization should be considered within the context of an integrated conservation strategy. The strategy should include management for habitat connectivity and conservation genetics. When necessary, assisted colonization could be a dimension of the overall strategy.

26.13.5. Forests

Because trees are genetically adapted to their local climates, rapid rates of climate change may challenge the capacity of tree species to adapt in place or migrate to new locations (Aitken et al 2008). Where there is adequate moisture, elevated CO2 and warmer temperatures may have positive effects on growth and productivity. However, for most forests in North America there are concerns about adverse impacts due to the risk of drought, fire, disease and infestations (Chmura et al 2011). Change in the climate will likely affect future species distribution, forest composition and forest structure. Entire forests in Canada, the United States and Mexico may be at risk.

Locally adapted forests near the northern limits of their species range may be able to track the poleward movement of climatic conditions to which they are adapted. Nonetheless, these migration rates may be too slow to keep pace with climate change, at least for some forest trees (Mohan et al 2009). Some species may migrate to higher elevations, but with sufficient warming these habitats may eventually disappear (Chmura et al 2011).

Wildfires, insects and disease will affect forests, perhaps bringing irreversible change to vulnerable ecosystems. Climate and weather are key factors contributing to epidemics of forest insects and pathogens. Climate change will directly affect plant stress that often precedes epidemics. Climate stress and epidemics have the potential to reduce tree and stand growth, and change the composition and structure of some forest ecosystems (Chura et al 2011).

High temperatures and current year drought are strongly associated with and increase in the number of wildfires and the area burned (Gillett et al 2004). Increases in the frequency, extent and severity of wildfires ultimately leads to greater damage, reduced growth and increased mortality in forest ecosystems (McKenzie et al 2004).

26.13.6. Firm Relocation

More frequent and intense weather extremes potentially will have significant impacts on ecosystems but also on social, economic, and industrial systems (Linnenluecke and Griffiths 2010). Potential future changes in climate and weather patterns may lie outside of the coping range of firms, and exceed their capacity to adapt (Carter et al 2007). Abrupt climate events, like extreme weather hazards, may overwhelm companies that are not prepared, while gradual changes may also reach thresholds that exceed the coping capacity of firms. Extreme events may force some firms to relocate while others may close.

There is an extensive literature assessing the capacity of individuals or communities to adapt to change in the climate and severe weather hazards (Smith 2007 and Warner et al 2008). A new literature is emerging to assess decision-making by private industry (Linnenluecke, Stathakis and Griffiths 2011). Consideration of relocation of companies due to change in the climate is considered within the established literature on firm location. This work traditionally focused on socio-economic factors like access to skilled workers, access to major markets and availability of critical inputs. In particular, this literature was concerned with establishing a sustainable competitive advantage.

The importance of weather considerations varies by industry and may be more evident for tourism, agriculture, forestry, fishery, insurance and the infrastructure management sector. Firms located in coastal communities may be vulnerable to sea level rise and more intense hurricanes. Those located in Alaska and northern Canada may struggle to cope with permafrost melt (Paepe and Melnikov 2001). Firms in Mexico and the southwestern United States appear increasingly vulnerable to drought and water shortage (Solomon et al 2009). Firm relocation may be required to ensure survival.

26.14. Governance

Since the 4AR, the governments, institutions, and the private sector across North America have begun putting in plans and taking other steps to adapt to climate change. This section briefly reviews adaptation responses, particularly in government, in the three countries.

26.14.1. Canada

Canada is a federal state with 10 provinces and 3 territories. This constitutional arrangement involving a complex division of powers and allocation of responsibilities among three levels of government is constantly under question, shifting at the margins, especially in areas of so called 'shared jurisdiction' (Gardner 1994; Morton 1996). To date, there is no overall strategy or grand design for climate change adaptation in Canada. The adaptation that is occurring is place- and region–specific, involving a diverse range of risks, sectors and ecosystems.

At the federal level, Canada has two major adaptation groups: (1) Adaptation Impacts and Research Service (AIRS) housed in Environment Canada; and (2) the Climate Change Impacts and Adaptation Division (CCIAD) within Natural Resources Canada. In 2007, Natural Resources Canada (NRCan) published the second national assessment, *From Impacts to Adaptation: Canada in a Changing Climate*. The report represents the most comprehensive assessment of the impacts of climate change in Canada to date. At the federal level, emphasis has not been on developing a national plan or strategy, but rather has been focused on climate change model and scenario development, as well as on providing research to the growing community of adaptation scientists and networks; the Canadian Climate Change Scenarios Network (CCCSN), for example, is Canada's state-of-the-art network that has contributed to the reports of the IPCC (IPCC 2007).

A number of Canada-wide initiatives have been supported on an interim or temporary basis. Following the release of the 2007 national assessment, NRCan announced a $35 million project to establish six Regional Adaptation Collaboratives (RACs) across Canada (with the requirement of matching provincial funding). A multitude of provincial, municipal and non-governmental players to develop their own plans, strategies and programs has also emerged. Over the past decade, several climate change consortiums have cropped up at the provincial level: Ouranos in Québec and Pacific Climate Impacts Consortium (PCIC) in British Columbia. Ontario established the Expert Panel on Climate Change Adaptation, which submitted its report in November 2009 containing a total of 59 recommendations, most of them specific action items addressed to a wide diversity of government departments. The report makes five major recommendations:

1) Launch a province-wide climate change adaptation action plan.
2) Establish a Climate Change Adaptation Directorate (CCAD).
3) Ensure that the CCAD has ongoing access to expertise.
4) Enhance climate change science and modelling capacity.
5) Identify dedicated funding for climate change adaptation initiatives.

More recently, at the municipal level, the Federation of Canadian Municipalities (FCM) has worked closely with ICLEI to promote mitigation and, of late, adaptation at the local level (FCM 2009). Their Partners for Climate Protection (PCP) program has 180 municipal governments actively involved in their five-milestone framework for reducing greenhouse gas emissions. The need for leadership is felt at the municipal level, with officials asking FCM for more information, resources and tools to aid them in adapting to climate change; this comes after several communities across Canada have initiated their own adaptation activities.

A specific example of incorporating adaptation is the Canadian Standards Association (CSA) and its National Permafrost Working Group, who developed a Technical Guide, CSA Plus 4011-10, on "Infrastructure in Permafrost: A Guideline for Climate Change Adaptation" that directly incorporates climate change temperature projections from an ensemble of climate change models. This Guide factors in climate change projections of temperature and precipitation and risks from melting permafrost to foundations over the planned lifespans of the structure. The guide also suggested possible adaptation options, taking into account the varying levels of risks and the consequences of failure for foundations of structures, whether buildings, water treatment plants, utilidors, towers, tank farms, tailings ponds or other infrastructure (NRTEE, 2009; Canadian Standards Association, 2010; see Chapter 9 case study 9.x.x on vulnerable regions: The Arctic)

Overall, in Canada, the current blend has been allowed to evolve almost unguided, with modest encouragement from the federal government. Leadership has emerged at both provincial and municipal levels across the country.

26.14.2. Mexico

Mexico is currently well under way to prepare an overall strategy to respond to climate change threats. Earlier government actions go back to 2005, when the *Inter-Secretarial Commission to Climate Change* (CICC – Comisión Inter-Secretarial de Cambio Climático) was created as a cross-sectoral government structure with a specific unit for adaptation (GT-Adapt). The CICC currently involves ten ministries, various technical counselling units, and their corresponding consultative bodies. It supports, among other things, "…*the development of public policy and integration of adaptation actions into all sectors' processes*" (CICC, 2011).

In addition, an attempt is being made by the present administration to link climate change and sustainability through the *National Plan for Development 2007-2012*, which includes four strategy lines providing the foundations for further government actions on climate change adaptation in Mexico. These lines are: 1) designing and developing capacities for adaptation; 2) developing climate scenarios at regional scale; 3) assessing impacts, vulnerabilities and adaptation to climate change in various socioeconomic sectors and ecological systems, and 4) promoting the divulgation of information about those impacts, vulnerabilities, and adaptation measures (PND, 2007). Corresponding government actions have been delivered through the *National Strategy for Climate Change 2007-2012,* which identifies priorities in climate change adaptation research and capacity development at various levels of government and society.

One of the implementation programmes that have been set up in context of this national strategy is the *Special Programme on Climate Change 2009-2012*. It seeks to build synergy with other government agencies and programmes to primarily address the impacts of climate change by delivering 142 adaptation strategies. So far, strategies on adaptation consist of setting up early warning systems, developing shared-risk schemes for agriculture and livestock activities, and creating insurance schemes against disasters. They also include campaigns for raising public awareness on various topics, including climate impacts on health, and natural resource degradation. Moreover, other sorts of strategies have also tried to support adaptation by opening up new opportunities for green investments (i.e. PES, alternative energy, and ecotourism).

Recently launched, the *Policy Framework for Medium Term Adaptation* (CICC, 2011) aims at framing national initiatives, such as the ones above mentioned, into a single national public policy approach on adaptation with a time-horizon up to 2030. It provides principles and guidelines for the integration of climate change adaptation across government departments. The four general principles are: 1) integrated land planning approach; 2) guaranteed human rights and equity; 3) public participation; and 4) access to information.

Advances are also being made at the sub-federal level. At the state level, many authorities have started their *State Plans for Climate Action*, with Veracruz, Distrito Federal, Nuevo Leon y Estado de Mexico having been fully developed. At the municipal level, the "*Safe Municipality*" programme aims at involving the local population in developing early warning systems and developing capacities for coping with disasters. For example, the Mexico City government has various initiatives, programmes and tools such as the *Local Strategy for Climate Action for the Federal District* and the *Climate Action Programme for Mexico City*. Although such initiatives pay more attention to mitigation than to adaptation, they put forward useful adaptive steps, reducing risks and increasing the knowledge of climate change impacts in urban areas.

Community level initiatives and strategies tend to be primarily developed by NGOs, such as Mexican Fund for the Conservation of Nature (Fondo Mexicano para la Conservacion de la Naturaleza) and Oxafm-Mexico, international development agencies and academia. Such work at this level is revealing the importance of diversified livelihoods, biodiversity, and social capital in rural communities' to adapt.

26.14.3. United States

In the United States, climate change adaptation has occurred at the federal level, at the state level, at the municipal level, and organizations. Each of these efforts has emerged relatively independent of the others, with no significant correlation of strategies or activities. Consequently, it is worth understanding each independent vein of activity to comprehend the entire landscape of climate change adaptation in the United States.

At the federal level, the most integrated effort to address the impacts of climate change across the federal government is the Interagency Climate Change Adaptation Task Force. Led by the White House Council on Environmental Quality (CEQ), the White House Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA), 21 other agencies helped develop a U.S. government-wide strategy on adaptation focused on science inputs to adaptation, agency processes, water resources management, insurance, and international assistance (White House, 2009).

The Task Force prepared a set of recommendations to the president that included five goals and a number of recommended actions to make progress toward each goal (White House CEQ, 2010). CEQ subsequently released "Instructions for Implementing Climate Change Adaptation Planning in Accordance with Executive Order 13514" (White House, 2011a) and a Support Document (White House, 2011b) to establish an agency climate change adaptation policy; to increase agency understanding of how the climate is changing; to apply understanding of climate change to agency missions and operations; to develop, prioritize, and implement actions; and to evaluate adaptations and learn from experience.

Some federal agencies, however, have already taken steps to address climate change adaptation prior to this broader interagency effort. The most comprehensive of these efforts was initiated by Secretary of the Interior Ken Salazar when he issued Secretarial Order 3289 – Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources. The order created the Energy and Climate Change Council to improve information-sharing and coordinate an integrated strategy across DOI agencies and bureaus. The order also created Climate Science Centers to integrate climate change information and management strategies in eight regions and 21 Landscape Conservation Cooperatives. These institutions were supposed to work with states and localities to inform science-based adaptation and mitigation strategies and adaptive management techniques (Pew Center on Global Climate Change, 2010; Smith et al., 2010; U.S. DOI, 2010). There are other, less comprehensive federal agency strategies that also predate the interagency efforts, such as the EPA's office of water's strategy (EPA 2008).

Additionally, a number of states have independently begun climate change adaptation planning. For example, the states of Alaska, Florida, and Connecticut all engaged in broad, stakeholder processes to identify climate sensitive programs, policies, and practices and develop plans of action to minimize or avoid the projected impacts of climate change. Other states have followed suit, but using less stakeholder-driven processes. Additionally, municipalities are beginning to tackle climate change adaptation. Most recently, county governments have started adaptation planning projects. Substantive conclusions about these efforts are premature as these projects are still being implemented.

Finally, the water sector has been considering adaptation to climate change since the mid-1990s (AWWA, 1996). Following early signals from professional organizations like the American Water Works Association, the Water Research Foundation, and the Water Environment Research Foundation, water utilities, both individually and in coalitions such as the Water Utility Climate Alliance, began conducting a number of activities related to climate change adaptation. These ranged from detailed assessments of their own vulnerability to climate change, to workshops for sharing best practices, to funding white papers to promote a water utility/climate research agenda (Barsugli et al 2011).

Nearly all of these efforts are in the initial stages of either planning or early implementation. Nevertheless, considerable adaptation activity continues, generally independent from activity as larger or smaller scales.

26.15. Limits to Predictability

Governments across North America are using climate change information to understand potential vulnerabilities to climate change and to support adaptation decision making. In doing so, they are relying on climate change projections at a state/provincial or even municipal scale and for specific years in the future. A key issue is the reliability of such climate model projections at the scales being used. This reliability is a product not only of the fidelity of the climate models to the processes operating in Nature, but also of the inherent predictability limits of the real climate system. These predictability limits are particularly acute for the regional-to-local spatial scales and near-term decadal time scales that many of these decisions are considering. This section will review some examples of use of climate model projections by governments, will assess the limits to predictability of future climate and related conditions, and conclude with a discussion about how adaptation decisions can be made in light of the limts to predictability.

State and local governments in the United States have used specific projections of climate change to help understand potential consequences of climate change and inform adaptation decision making. Specific examples are given below. The use of the scenarios appears to vary. In some cases, they are intended to inform decision making, while in others they are referred to as planning scenarios. No matter the stated intent, use of such specific climate projections can result in planning around a climate outcome that does not unfold in the real future. The states of California (California 2009) and Washington (Washington, 2011), and New York City (New York City, 2009) are used as examples.

26.15.1. Sea-Level Rise

Different projections of sea level rise were used by the two states and New York City. The California adaptation strategy uses a range of sea level rise of 12 to 18 inches (0.30 to 0.46 meters) by 2050 and 21 to 55 inches (0.53 to 1.4 meters) by 2100. Washington state, citing Mote et al., 2008, gives projections which account for local differences in subsidence and uplift. Their projections are " -9 to +35" (-0.23 to 0.89 meters) for the Northwest Olympic Peninsula, +2 to 43" (0.05 to 1.09 meters) for the central and southern coast, and 13‖ (+6 to 50") (0.15 to 1.27 meters) for Puget Sound (Washington, 2011a) by the 2080s [not clear from document; but other projections are for 2080].

In contrast, New York City uses two sets of sea level rise projections, based on recommendations from the New York Panel on Climate Change. One projection is consistent with the IPCC 4AR projections and the other assumes rapid ice melt. The first projections are for 7 to 12 inches (0.18 to 0.30 meters) by 2050 as 12 to 23 inches (0.30 to 0.58 meters) by 2100. The rapid ice melt projections are 19 to 29 inches (0.48 to 0.74 meters) by 2050 and 41 to 55 (1.0 to 1.4 meters) inches by 2100. In addition, the New York City plan uses projections of change in frequency of coastal flooding: the current 1 in 100 year coastal flood will become the 1:15 to 1:35 year coastal flood by 2100.

26.15.2. Changes in Temperature and Precipitation

All three adaptation planning documents refer to specific changes in temperature and precipitation. The California plan states these are planning assumptions.

The New York City plan states that heat waves, currently defined as three consecutive days over 90oF (32.2°C), will be approximately 2.5 to 4 times more frequent by 2100.

The Washington advisory groups assume a number of changes in climate. The Natural Resources Advisory group assumes that areas with limited moisture for forests will increase by a minimum of 32% by the 2020s and an additional 12% in both the 2040s and 2080s. The Human Health and Security advisory relied on projections of a 5oF (2.8°C) warming by 2059 in southeastern Washington and a decrease of snowpack on April by 40% (Washington, 2011c). The Species and Habitat workgroup cited temperature increases of 1.1 to 3.4°F (0.6 to 1.9°C) by the 2020s, 1.6 to 5.2°F (0.9 to 2.9°C) by the 2040s, and +2.8 to 9.7°F (1.6 to 5.4°C) by the 2080s, relative to 1970-1999; a 1 to 2% increase in annual precipitation, but wetter autumns and winters and drier summers; decline in April 1 snowpack of 37 to 44% by the 2040s and 53 to 65% by 2080s; a doubling to quadrupling of high water temperatures that would block salmon migration by the 2080s; and a doubling of area subject to forest fires by the 2040s and tripling by 2080s.

The California adaptation strategy assumed that a drier climate is highly likely, "For planning purposes, eleven of the twelve simulations selected for the 2008 California Climate Change Impacts Assessment deliberately project a future marginally to considerably drier by mid-century, while only one simulation projects a slightly wetter future." (California, 2009, p. 82). The drier models project a 12 to 35% decrease in precipitation by 2050. Temperatures are projected to increase by 2 to 5oF (1.1 to 2.8oC) by 2050 and 4 to 9o F (2.2 to 5.0oC) by 2090. The Department of Water Resources projects that snowpack will 25 to 40% by 2050. Change in hydroelectric production range from a reduction of 19% to an increase of 5%, although no date is given.

26.15.3. Reasons for Limits to Predictability in North American Climate

These examples highlight the fact that (1) many adaptation decisions are being made based on the results of specific climate model simulations, (2) these decisions are being made based on projected changes in regional- or local-scale climate, and (3) some of these decisions are being made based on projected changes over the next 1-3 decades. These examples support the observation made elsewhere (e.g., (Cane 2010) NSF EaSM document) that decadal and regional-to-local climate predictions are in particular demand by decision-makers. However, this demand is in direct conflict with the inherent predictability of the real climate system, which is greatest for short timescales that are dominated by the current state of the system (and not by changes in external forcing), or long timescales that are dominated by changes in forcing (and not by the initial state of the system) (e.g., (Hawkins and Sutton 2009; Cane 2010)). In contrast, the decadal and regional-to-local information that is being used as the basis for adaptation decisions falls at the scales where the real outcome in Nature will be influenced by both the initial conditions and the change in external forcing, and by the chaotic internal variability that can dominate the regional-scale spread in near-term climate model projections (Hawkins and Sutton 2009; Hawkins and Sutton 2010).

Uncertainty in future climate change is often partitioned into uncertainty from three primary sources: (1) internal climate system variability ("internal variability uncertainty"), (2) the pathway of future radiative forcing ("scenario uncertainty"), and the understanding of climate system processes ("model uncertainty") (e.g., (Hawkins and Sutton 2009)). Analyses of the CMIP3 global climate model ensemble show that internal variability dominates the spread between the realizations for regional spatial scales on lead times of less than four decades (Hawkins and Sutton 2009; Hawkins and Sutton 2010). In particular, internal variability accounts for more than 40% of the temperature spread and more than 60% of the precipitation spread over many regions of the globe for a lead time of 3 decades.

The spatial and temporal scales on which vulnerability and adaptation decisions are currently being based therefore fall where the noise in the climate system is the strongest and they may in fact exceed the limits of predictability of the real climate system. In addition, the fact that these calculations are made over relatively large regional areas further highlights the potential limits of predictability, as many decisions are being made to plan for climate change on even smaller spatial scales, where there can be even greater variation in the magnitude of climate change (e.g., (Diffenbaugh et al. 2005; Rauscher et al. 2008; Barsugli et al., In Press)). Further, while scenario uncertainty dominates the model spread in both global and regional temperature change in the late 21st century, model uncertainty dominates the spread in regional precipitation change, adding additional uncertainty in regional climate change beyond the inherent limits of predictability imposed by the internal variability of the climate system.

26.15.4. Possible Ways to Make Decisions within Context of Limits to Predictability

A number of approaches to decision making exist within the context of the predictability limits of the real climate system. These include:

1) Remove potential climate changes from consideration.
2) Restrict actions to the subset that confers benefits in the present climate.
3) Focus actions on the subset that increases resilience to a broader climate envelope than currently exists.
4) Invest in actions that increase capacity to respond to a diversity of climate outcomes the outcome is known in the future once.

The analysis above shows that as of now, it is not possible to forecast exactly how climate will change at a municipal or even provincial or state level decades into the future. While there are limits to predicting climate change at the temporal and spatial scales at which many adaptation decisions will need to be made, there are many possibilities for decreasing vulnerability to climate change – even in spite of these uncertainties.

Decisions are routinely made on managing many systems which will be affected by changes in socioeconomic conditions, even though there is uncertainty about how key socioeconomic variables will change. Transportation systems, water supply and sanitation systems, schools, and many others systems are planned and built in the midst of uncertainty about future population levels, demographics, income, preferences, technologies and other factors.

There are a number of approaches to climate change adaptation A common theme is to increase flexibility of systems so they provide services across a wide array of potential future climate conditions. One way to do this is to rely on mechanisms that respond to changing environmental (and other) conditions. For example, use of market based systems to allocate resources will be more responsive to changing supply and demand conditions than fixed allocations. Use of “green infrastructure,” which relies on natural systems such as wetlands in regulating water flows, can be more responsive to changing climatic conditions than hard infrastructure. An additional approach is encouraging change in use, such as rolling easements to facilitate removal of coastal infrastructure as sea levels rise (Titus cite)

Another theme that has been widely advocated is reforming or otherwise changing policies that have the effect of promoting risky or maladaptive behavior under current climate conditions. Areas currently vulnerable to floods or droughts are often likely to become more vulnerable to these events under climate change.

Other approaches to adaptation that have been advocated include *robust decision making*, in which decision makers seek out adaptations that are effective across a wide variety of climate change conditions (Groves and Lempert, 2007; Groves et al., 2008). *Adaptive management* is a process by which management decisions can be regularly revisited based on monitoring conditions, new science, or other information (National Research Council, 2004; also called “real options” Means et al., 2010). *Portfolio management*, which is not applicable for all climate change adaptations, involves having many options to use as needed. For example, communities facing the risk of future water shortages may have available numerous options to reduce demand or increase supplies.

26.16. Summary and Conclusions

[to be developed]

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[incomplete, and yet to be integrated]

Note to Reviewers

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Section 26.1

TBD

Section 26.2

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Section 26.5

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Section 26.7

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Sections 26.8 though 26.16

TBD

Table 26-1: Some dimensions and determinants of urban vulnerability.

Climate parameter	**Systems**	**Impacts (changes in)**	**Determinants of adaptive capacity/resilience**	
			City wide	**Individual level**
Sea level rise	Health	Disease	Land use planning	Age
Temperature	Energy	Mortality	Urban design	Gender
Precipitation	Built environment	Water availability	Transportation	Ethnicity
Heat waves	Economic sector	Air & water quality	Water, sanitation, energy, waste	Migration status
Surges	Demographic group	Economic disruptions	Housing	Income
	Infrastructure	Migration	Social networks	Education
	Transport	Infrastructure damages	Community based organizations	Health conditions
	Hinterland	Livelihoods	Policy (emergency) response	Knowledge, experience
	Ecosystem services		Governance	Savings
				Insurance

Source: Romero-Lankao 2011

Figure 26-1: Water stress by hydrological-administrative region, 2008. Source: Water Statistics

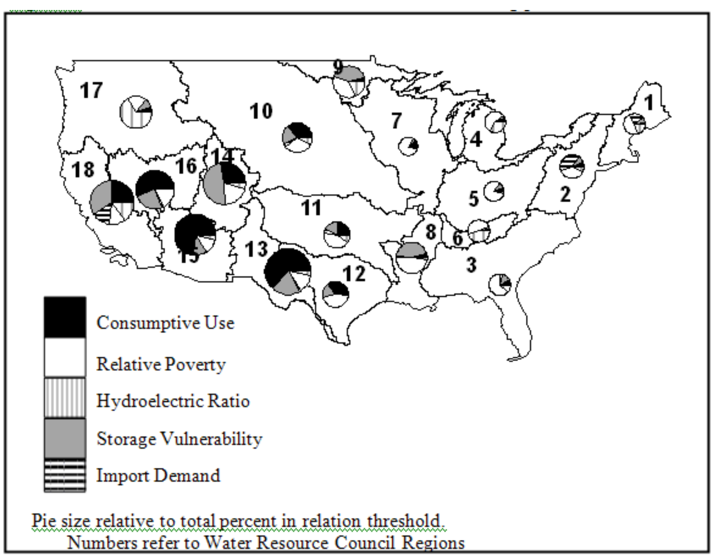

Figure 26-2: Socio-economic indicators under current climate using pie charts.
(NOTE THIS IS JUST A PLACEHOLDER FIGURE)

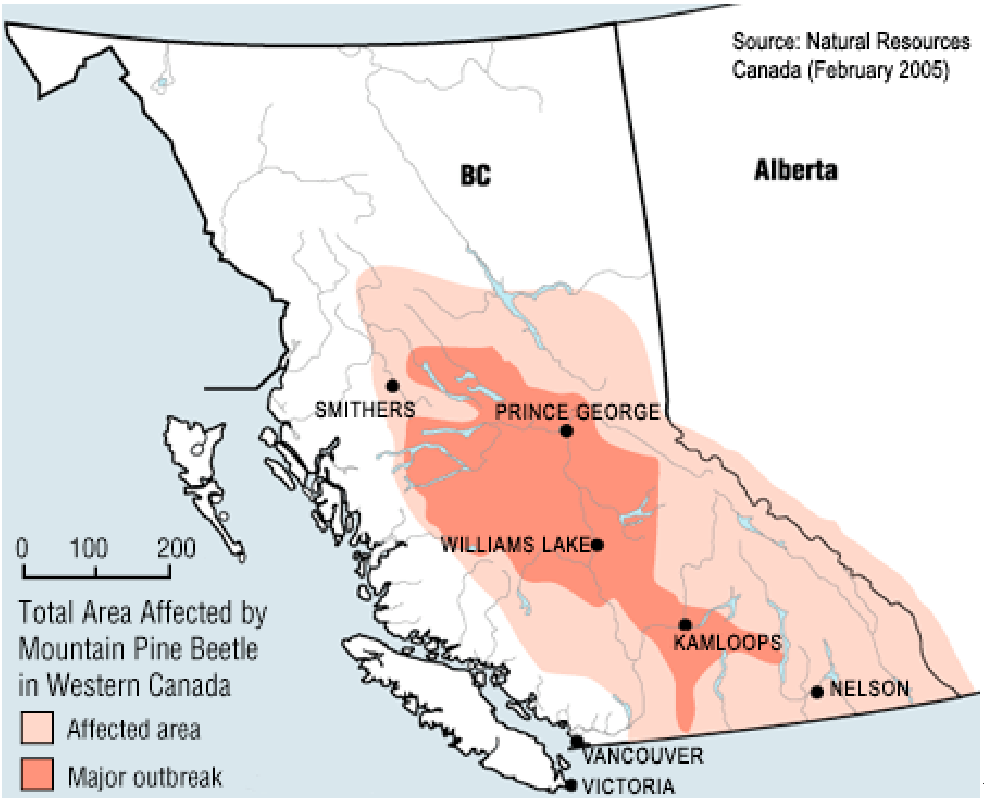

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Figure 26-3: Title? Source*:* Natural Resources Canada, http://mpb.cfs.nrcan.gc.ca/map_e.html

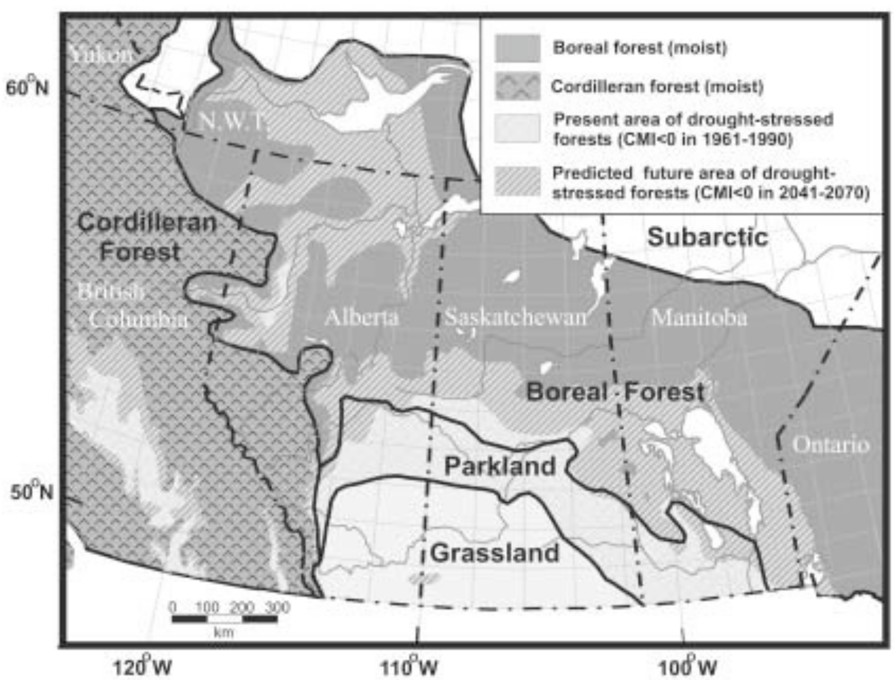

Figure 26-4: Title? Source: Hogg and Bernier, ____.