Chapter 26. North America

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Executive Summary

Changes in climate trends in North America include **i**ncreased occurrence of severe hot weather events over much of the U.S., decreases in frost days, increases in heavy precipitation over much of North America, and reductions in spring snowpack along with an earlier peak runoff over many areas (*very high confidence*). **It is *highly likely* that global average increases in temperatures of at least 2°C (above the pre-industrial baseline) will lead North America to experience a frequent occurrence of**:

- **Extreme heat** during the summer in most areas
- **Low snow years and shifts towards earlier snowmelt runoff** in areas where seasonal snow cover is present in the current climate. [26.2]

It is *likely* that global warming of approximately 4°C will cause increases in annual precipitation in northern North America and decreases in annual precipitation in southern North America.

Attribution of observed changes in North America to anthropogenic climate change has been established for some physical systems (e.g., snowpack) and some ecosystems (e.g., forests dieback and pests distribution) (*very high confidence*). Evidence of anthropogenic climatic influence on agriculture, water, and human settlements is less clearly established.

Impacts of climate variability such as floods, decreased water availability, and increased salinity of coastal water supplies, which are exacerbated by other anthropogenic drivers, are observed in most areas of North America (*high confidence*). Water supply deficits are conducive to adaptive response, with many hard and soft approaches to adaptation currently available; adaptive responses to flooding and water quality concerns are more limited (*high confidence*). [26.3] **It is *very likely* that the 21st century will witness:**

- **Decreases in water quality, and increases in flooding and droughts, throughout most of North America** under climate change, and these impacts exacerbated by other anthropogenic drivers.
- **Decreases in water supplies for urban areas and irrigation in selected areas** of North America with confounding effects of development, except in general for *southern Mexico*; the northwest and northeast coastal USA; and west and east Canada. [26.3, 26.8]

Climate change is already affecting many ecosystems across North America. A global increase of 2°C would have widespread adverse impacts on those ecosystems (*high confidence*). Forests are being affected by fire, drought, pests, and other climate-related stresses. Coastal zones are being affected by multiple and often interacting climate stresses including higher temperatures, ocean acidification, coral reef bleaching, sea level rise, storm surges, and storms. Climate stresses will *likely* reduce biodiversity and ecosystem services. [26.4]

Without adaptation, projected changes in temperature, precipitation, and extreme events would result in notable productivity declines in major North American crops by the end of the 21st Century (*very high confidence*). Given that North America is a significant source of global food supplies, if projected productivity declines here are not addressed with substantial investments in adaptation, there will likely be a negative effect on global food security (*medium confidence*)**.** Adaptation may ameliorate many climate impacts to North American agriculture, but the institutional support mechanisms currently in place are insufficient to ensure effective, equitable and sustainable adaptation strategies (*medium confidence*). [26.5]

Human *health impacts* from extreme events have been observed. Heat extremes currently result in increases in mortality and morbidity in North America, with impacts that vary by age and socioeconomic factors (*very high confidence*). Coastal storm events periodically cause excess mortality and morbidity via a range of direct and indirect pathways in North America, particularly along the east coast of the United States, and the gulf coast of both Mexico and the United States (*high confidence*). The effect of increasing heat extremes on human health will depend on the pace of adaptation, which is unknown. Given current levels of adaptation, there are *likely* to be increased health impacts from heat extremes among vulnerable communities, populations, and individuals. Conditional on an increase in storm severity under a changing climate, there are likely to be continued human health risks in the absence of specific adaptation planning. [26.6]

Several social and economic impacts observed in North American human settlements have been attributed, with different degrees of certainty, to climate-related processes (*high confidence*). These processes include but are not limited to sea level rise, changes in temperature and precipitation, and occurrences of such extreme events as droughts and storms. [26.8]

Differences in the severity of climate impacts on human settlements are strongly influenced by context-specific social and environmental factors and processes (*high confidence*). Some of these processes (e.g., the legacy of previous and current stresses) are common to urban and rural settlements, while others are more pertinent to some types of settlements than others. For example, concentrations of populations, economic activities, cultural amenities, and built environments in highly exposed urban locations such as coastal and dry areas creates higher hazard risks in cities; whereas, for many small rural areas, geographic isolation and institutional deficits are key sources of vulnerability. **Among the most vulnerable are indigenous peoples** due to their unique history and relationship to the land, and Mexico City due to the high density of population combined with several socio-economic and environmental sources of vulnerability (*high confidence*). [26.8]

Many infrastructural elements across North America are currently vulnerable to extreme weather events and, unless investments are made to strengthen them, would be more vulnerable to climate change (*medium confidence*). Infrastructures, particularly in water resources and transportation, are in many cases deteriorating, thus more vulnerable to extremes than strengthened ones. Extreme events have caused significant damage to infrastructure in many parts of North America. Risks to infrastructure are particularly acute in Mexico. [26.7]

Most sectors of the North American economy have been affected by and responded to extreme weather, including hurricanes, flooding, and intense rainfall (*high confidence*). There are, however, few examples of proactive adaptation anticipating future climate impacts, and these are largely found in sectors with longer term decisionmaking, including energy and public infrastructure. Lessons learned are not well-documented in the literature. [26.7]

There is an emerging concern that dislocation in one sector of the economy may have an adverse impact on other sectors due to supply chain interdependency (*medium confidence*). [26.7]

Slow onset perils – like sea level rise, drought, and permafrost melt – are another emerging concern for some sectors, with large regional variation in awareness (*medium confidence*). There is little published literature about impacts and adaptation experience. [26.7]

Different economic and demographic sectors are responding to climate change (e.g., purchasing additional insurance, reinforcing homes to withstand extreme weather). **While different tiers of government are assessing their climate vulnerabilities and designing adaptation actions and programs, there has been more leadership in adaptation planning at the local level.** Many governmental responses are in diagnosis and planning stage and have not yet moved into implementation (*high confidence*). [26.8, 26.9]

Important barriers exist to effective adaptation such as path dependency**,** lack of assets and options, lack of funding and staff, lack of horizontal and vertical coordination, asymmetries in access to information, lack of social capital, and top-down decisionmaking (*high confidence*). [26.8, 26.9]

Climate change impacts can hamper progress towards sustainability and have the potential to exacerbate existing challenges such as deficits in infrastructure or in institutional capacity to promote the health and well-being of human populations (*high confidence*). [26.7, 26.9]

Adaptation actions at the local level throughout North America have the potential to result in synergies, conflicts, or tradeoffs with mitigation and other development actions and goals (*high confidence*). For example, reductions in greenhouse pollutant emissions will in many cases bring proximal benefits for human health by reducing health-damaging air pollution concentrations. Conversely, sea walls can protect coastal properties, yet may negatively affect the structure and function of coastal ecosystems. [26.8]

26.1. Introduction

This chapter assesses literature on observed and projected impacts, vulnerabilities and risks as well as on adaptation practices and options in three North American countries: Canada, Mexico and USA. (The North American Arctic region is assessed in Chapter 28: Polar Regions). North America ranges from the tropics to frozen tundra, and contains a diversity of topography, ecosystems, economies, governance structures and cultures. As a result, risk and vulnerability to climate variability and change may differ considerably across the continent depending on geography, scale, hazard, social, socio-ecological or ecological systems, demographic sectors, cultural values and institutional settings (Table 26-1). This chapter seeks to take account of this diversity and complexity as it affects and is predicted to affect vulnerability and risk across North America.

No single chapter would be adequate to cover the range and scope of the literature about climate change impacts, vulnerabilities and adaptations in our three focus countries. (Interested readers are encouraged to review the following reports: Canadian Climate Report; (SEMARNAT-INECC, 2012; NCADAC, 2013). We, therefore, attempt to take a more integrative and innovative approach. In addition to describing current and future climatic and socioeconomic trends of relevance to understanding risk and vulnerability in North America (section 26.2), we contrast climate impacts, vulnerabilities and adaptations across and within the three countries in the following key sectors: water resources and management (section 26.3); ecosystems and biodiversity (section 26.4); agriculture and food security (section 26.5); human health (section 26.6); and infrastructures and other economic sectors (section 26.7). We use a comparative approach to explore the factors and processes associated with differences and commonalities in vulnerability, risk and adaptation between urban and rural settlements (section 26.8); and to illustrate and contrast the nuanced challenges and opportunities adaption entails at the city, the state and the national level (sections 26.8.4 and 26.9; Box 26-3). We highlight two case studies that cut across sectors, systems or national boundaries. The first, on wildfires (Box 26-2), explores some of the connections between climatic and physical process (e.g., decadal climatic oscillation, droughts, wildfires and pests) and across systems and sectors (e.g., fires direct and indirect impacts on local economies, livelihoods, built environments and human health). The second takes a look at the world's longest border between a high-income (US) and middle income country (Mexico) and briefly reflects on the challenges and opportunities of responding to climate change in a transboundary context (Box 26-1).

We close with a section (26.10) summarizing key multi-sectoral risks and uncertainties at the regional level and discussing some of the knowledge gaps that will need to be filled by future research.

Findings from the Fourth Assessment Report

This section summarizes key findings on North America, as identified in chapters 13 and 14 of the Fourth IPCC assessment focused on Mexico (Magrin *et al*., 2007) *and Canada and the USA respectively* (Field *et al*., 2007). Over the past decades, economic damage, from severe weather has increased dramatically, due largely to the high value of infrastructures at risk in Canada and the US (14.2) (*very high confidence*). Increases in the frequency of very heavy rains were identified in central Mexico [13.2.4.1] (*high confidence*).

Although Canada and the US have considerable adaptive capacity, their vulnerability depends on the effectiveness and timing of adaptation and the distribution of capacity, which vary spatially and among sectors [14.2.6, 14.4] (*very high confidence*). Mexico has early warning systems and risk analysis in such areas as agriculture, human health and water resources, yet it faces planning and management barriers (*high confidence*). In Canada and the US, based upon long standing traditions and institutions, a decentralized response framework has resulted in adaptation that tends to be reactive, unevenly distributed, and focused on coping with rather than preventing problems [14.5] (*very high confidence*).

Coastal communities and habitats in the three countries will be stressed by sea level rise, storm-surge flooding and other climate change impacts interacting with developmental and environmental stresses, such as salt intrusion, pollution, population growth and the rising value of infrastructure in coastal areas (Mexico: [13.4.4]) (*high confidence*); (US and Canada: [14.2.3; 14.4.3) (*very high confidence*).

Land use changes in Mexico have intensified land degradation, and increased the vulnerability of coastal mangroves and estuaries [13.2.3] (*high confidence*). Significant species extinctions in many tropical areas of Mexico are projected [13.4.1] (*high confidence*). While increases in grain yields in U.S. and Canada are likely [14.4.4], in Mexico the picture is mixed for wheat and maize, whose behavior is more erratic depending on the scenario that plays out [13.4.2] (*medium confidence*).

Millions in Mexico are projected to be at risk from the lack of adequate water supplies [13.4.3] (*medium confidence*), while in the US and Canada rising temperatures will diminish snowpack and increase evaporation, thus affecting seasonal availability of water [14.2.1] (*very high confidence*). Together with higher demand from economic development, agriculture and population growth will impose further constrains to over-allocated water resources, increasing competition among agricultural, municipal, industrial and ecological uses [14.4.1; 14.4.6] (*very high confidence*).

Changes in geographical distribution and transmission of diseases have been projected for the three countries. Mexico will likely face changes in the geographical distribution of dengue [13.4.5], while the US and Canada are likely to see an increase in risk and geographic distribution of vector-borne infectious diseases, including Lyme disease and West Nile virus. Warming and climate extremes are also likely to increase respiratory illness, including exposure to pollen and ozone [14.4]. Hot temperatures and extreme weather in Canada and the US are likely to increase adverse health impacts from heat-related mortality. Climate change impacts on infrastructure and human health and safety in urban centers of Canada and the US will be compounded by aging infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an aging population [14.4; 14.5] (*very high confidence*).

A warmer future with drier soils and longer growing seasons will also likely increase and intensify wildfire and insect outbreaks in Canada and the US. Pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter ecosystem structure, function and services [14.2; 14.4] (*very high confidence*).

Without increased investments in such countermeasures as early warning and surveillance systems, air conditioning, access to health care, pollution, storm-related fatalities and injuries, and infectious diseases, hot temperatures and extreme weather in Canada and the US are likely increase adverse health impacts from heat-related mortality. Furthermore, climate change impacts on infrastructure and human health and safety in urban centers of Canada and the US will be compounded by aging infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an aging population [14.4; 14.5] (*very high confidence*).

How vulnerable North America is depends upon the effectiveness of adaptation and the distribution of capacity. Both of these are unevenly distributed [14.5]. While both chapters see 'mainstreaming' climate issues into decision making as key to successful adaptation [14.5; 13.5], chapter 13 suggests mainstreaming adaptation strategies with national / regional sustainable development plans [13.5] as a key step towards meeting adaptation needs.

26.2. Key Trends

26.2.1. Demographic and Socioeconomic Trends

26.2.1.1. Current Trends

Canada, Mexico and USA share commonalities but also differ in key dimensions shaping vulnerability and adaptation such as population dynamics, economic development, and institutional capacity. Population growth has been slower in Canada and USA than in Mexico (United Nations, 2011). Yet population growth in Mexico also decreased from 3.4 percent during 1970-1980 to 1.5 percent during the last decade due to lower birth rates, which were offset by gains in life expectancy. All three countries have aging populations. In 2010, 20% of the population in Canada was 60 years and older, compared to 18% in the USA, and 9% in Mexico (United Nations, 2011). Urban populations have grown faster than rural populations resulting in a North America that is highly urbanized (Canada 84.8%, Mexico 82.8% and USA 85.8%). These urban populations are also expanding into peri-urban spaces, producing rapid changes in *population patterns* and land use that can exacerbate climate risks (Eakin *et al*., 2010; Romero-Lankao *et al*., 2012).

Similarly, while concentrations of growing populations, infrastructures and sectors in urban areas can be a source of risk, geographic isolation of rural populations can be a source of sensitivity that is aggravated by high dispersion levels (Figure 26-1; section 26.8). Rural populations might experience an increased sensitivity to climate events, as they face smaller labor markets, lower income levels and reduced access to public services. Rural poverty could also be aggravated by agricultural changes, particularly in Mexico where 65% of the rural population is poor, agricultural production is seasonal and most households lack insurance (Scott, 2007). Food price increases, which may also result from climate events, would contribute to poverty levels in urban and rural areas (Lobell *et al*., 2011; World Bank, 2011).

[INSERT FIGURE 26-1 HERE
Figure 26-1: Current and future populations in North America. While concentrations of growing populations, infrastructures, and sectors in urban areas can be a source of risk, geographic isolation of rural populations can be a source of sensitivity that is aggravated by high dispersion levels. Source: Lutz, 2007.]

The three countries have become more economically integrated following the 1994 North American Free Trade Agreement. For instance, prior to a 2007-2008 reduction in trade, the US-Mexico border was a region of dynamic growth in industry, employment and global trade of agricultural and manufactured goods (Robertson *et al*., 2009). However, differences in such determinants of adaptive capacity as levels of human development within and across countries, institutional asymmetry and fragmentation can be a source of risks and opportunities in managing trans-border environmental resources and vulnerability issues (Scott and Banister, 2008; Wilder *et al*., 2010) (Box 26-1).

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Box 26-1. Adapting in a Transboundary Context: the Mexico-US Border Region

Extending over 3169 km (1969 miles), the border between the United States and Mexico is one of the longest between a high-income and middle income country, and offers both challenges and opportunities to respond to climate change in a transboundary context. Sharing common climate regimes, natural resources, regional economies and urban areas (Wilder *et al*., 2013), in recent years the region has been subject to severe droughts, and floods, and these events are likely to become more frequent and intense as climate change progresses (Wilder *et al*., 2013). Additionally, there is a prevalence of incipient or actual conflict, given by currently or historically contested land boundaries or natural resources (Udall and Varady, 1993) and management of shared resources by distinct entities (Megdal and Scott, 2011).Climate change, therefore, as it interplays with socio-economic changes in the area, will most likely bring significant consequences for water resources, ecosystems, human health, and rural and urban settlements.

Changing Socio-Economic and Physical Conditions

The population of the Mexico-US Border Region is rapidly growing and urbanizing, with population increasing from just under 7 million in 1983 to over 15 million in 2012. Since 1994, rapid growth in the area has been fueled by a fast-paced economic change resulting from the passage of the North American Free Trade Agreement (NAFTA) (U.S. EPA and Secretaría de Medio Ambiente y Recursos Naturales, 2011; U.S. EPA, 2012). Between 1990 and 2001 the number of maquiladoras in Mexico had more than doubled, from 1700 to nearly 3,800, *with* 2,700 in the border area. By 2004, it was estimated that more than one million Mexicans were employed in the more than 3,000 *maquiladoras* located along the border.

Notwithstanding this explosive growth in economic activity and population in the region, challenges to adaptive capacity include high rates of poverty in a landscape of uneven economic development (Wilder *et al*., 2013). Large sections of the urban population live in informal housing lacking the health and safety standards needed to respond to hazards, and with no insurance (Collins *et al*., 2011). Any effort to increase regional adaptive capacity needs to take existing gaps into account.

Climate change is projected to put additional stresses to the region (Wilder *et al*., 2013), currently characterized by high temperatures and aridity, with about half of its precipitation coming in the summer monsoon and that has experienced particularly dry conditions in recent years. For example, the current drought, affecting large areas on both sides of the border is the most extreme in over a century of recorded precipitation patterns for the area (Cayan *et al*., 2010; Seager and Vecchi, 2010b; Nielsen-Gammon, 2011). Streamflow in already oversubscribed rivers such as the Colorado and Rio Grande has also decreased, threatening water resources. Climatological conditions for the area have been particularly unprecedented, with sustained high temperatures that may exceed any experienced for 1,200 years. While these changes cannot conclusively be attributed to anthropogenic climate change, they are consistent with climate change projections (Woodhouse *et al*., 2010).

Ecosystems

Population growth, economic development and urbanization are already fragmenting and degrading the region’s highly diverse habitats, species and ecosystems, such as the California saga and chaparral, the Sonoran and Chihuahuan deserts, sensitive wetlands and the Tamaulipan mezquital (Wilder *et al*., 2013). Of the region’s over 6,500 animal and plant species, 235 on the Mexican side are classified in a risk category and 85 are considered endangered under Mexico’s law. While on the U.S. side, 148 species are listed as endangered under the U.S. Endangered Species Act. (U.S. EPA and Secretaría de Medio Ambiente y Recursos Naturales, 2011).

Human Health

In the absence of adequate policies and governance structures, upward trends in population growth and economic activity have brought with them more pollution sources, including motor vehicles, industries and power plants (Varady *et al*., 2002; Sarnat *et al*., 2012). Heavy diesel trucking is also concentrated along several highways and border crossings, creating local hotspots for fine particle pollution (Svendsen *et al*., 2012). Border monitoring stations show that there were some days with violations of ozone or PM10 air quality standards in the past five years, but with variations from year to year (World Health Organization, 2007).

As climate change enters the equation, it may impact human health in the region in diverse ways: For instance, long-term draught in the region increases respiratory impacts from wind-blown dust. Rising temperatures increase ozone levels (U.S. EPA and Secretaría de Medio Ambiente y Recursos Naturales, 2011). As climate change interacts with socio-economic factors in the region, the human health stressors may be compounded.

Adaptation Challenges

In the fragile ecosystems of this region, opportunities and challenges, resources and environmental and health impacts are shared across international borders, creating the need for cooperation among local, national and international actors. Although there are examples of efforts to manage trans-border environmental problems (Wilder *et al*., 2010; Megdal and Scott, 2011), barriers to effective cooperation and collaboration exist such as different governance structures —centralized (Mexico) versus decentralized (United States); institutional fragmentation; asymmetries in the use and dissemination of information, and language (Wilder *et al*., 2013).

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26.2.1.2. Future Trends

Population in North America is projected to keep growing over the next decades and reach between 531.8 and 660.1 million by 2050 based on respective B2 and A2 scenarios (Lutz *et al*., 2007). The aging of population is also projected to progress, particularly in Mexico, so that by 2050, between 26.9% and 23.4% of the population in Canada, 18.4 % and 12.4% Mexico and 20.9% and 17.3% in the USA is projected to be elderly under respective B2 and A2 scenarios (Lutz *et al*., 2007). The elderly are more sensitive to extreme weather events (heat waves in particular, Figure 26-2) and the risks are still greater for those living alone (Martiello and Giacchi, 2010; Diffenbaugh and Scherer, 2011; Romero-Lankao, 2012; White-Newsome *et al*., 2012). Increases in the numbers of single-person households and female-headed households may also exacerbate the vulnerability of populations. Institutional capacity may also be limited by challenges posed by aging populations and a resulting stress on health and economic performance.

[INSERT FIGURE 26-2 HERE
Figure 26-2: Projected changes in the intensity of the worst heat events, as simulated by CLMU for urban grid cells: a) near term (2020-2039) relative to present-day climate (1980-1999); b) end of the 21st century (2080-2099) relative to present-day climate (1980-1999). Source Wilhelmi et al. (forthcoming).]

While many demographic factors have bearing on impacts and adaptation, three other shifts are projected to influence impacts, vulnerabilities and adaptation to climate change in North America: urbanization, migration, and economic disparity. With small differences between countries, both the concentration of growing populations in some urban areas and the dispersion of rural populations in many smaller settlements are projected to continue to define North America by 2050 (Figure 26-1b). For instance, according to projections, giving no consideration to global warming, between 2005 and 2030 the population of Mexico-City-Metro-Area will increase by 17.5%, while between 2007 and 2030 available water will diminish by 11.2% (Romero-Lankao, 2010). Conversely, education, a key determinant of adaptive capacity, is expected to expand to low-income households, minorities, and women, which could increase the capcity of households to cope with environmental risks and have a positive impact on economic growth (Goujon and Lutz, 2004). However, a continued growth in economic disparity and poverty could hinder such improvements. Inequality in Mexico is larger, having a Gini index (a measure of economic disparity) of 0.56, in contrast to 0.317 for Canada and 0.389 for USA (OECD, 2010b). Limited economic growth expected in the short run for the region would not help to reduce the income gap across and within countries (OECD, 2010a). Mexico, which already has a markedly higher poverty rate than Canada or the U.S., is one of five developing countries in the world that is projected to experience the highest increases in poverty due to climate-induced extreme events (52% increase in rural households; 95.4% in urban wage-labor households) (CMIP3, A2) (Ahmed *et al*., 2009).

Migration can be influenced by multiple factors, and isolating climate change as a cause is difficult. However, changes in climate can influence decisions to migrate, and migration flows themselves have implications for climate change impacts and vulnerability. This because the arrival migrants can increase pressure on climate sensitive urban regions (Hugo, 2011). In North America, one of the most significant migration flows that was influenced, in part, by climate change was the outmigration of many in the Mexican agrarian sector (Saldaña-Zorrilla and Sandberg, 2009). Lack of capital has been the key inducement for migration in response to historic Mexican droughts (Fraser, 2007; Gilbert and McLeman, 2010). However, current outmigration from regions in Mexico experiencing recurrent disasters outpaces migration from regions with lower socio-economic status (Saldaña-Zorrilla, 2006) pointing to concerns for health and safety as another driver of migration resulting from changes in climate.

26.2.2. Physical Climate Trends

Some processes important for climate change in North America are assessed in other Chapters of AR5, including WGI Chapter 2 (*Observations: Atmosphere and Surface*), WGI Chapter 14 (*Climate Phenomena and their Relevance for Future Regional Climate Change*), WGI Annex I (*Atlas of Global and Regional Climate Projections*), and WGII Chapter 21 (*Regional Context*). In addition, comparisons of emissions, concentrations, and radiative forcing in the RCPs and SRES scenarios can be found in WGI Annex II (*Climate System Scenario Tables*).

26.2.2.1. Current Trends

Chapter 2 of WGI assesses observations of the climate system. Observations show increases in the occurrence of severe hot events over the U.S. over the late 20th century (Kunkel *et al*., 2008, WGI 2.6.1), a result in agreement with observed late-20th-century increases in extremely hot seasons over a region encompassing northern Mexico, the U.S. and parts of eastern Canada (Diffenbaugh and Scherer, 2011). These increases in hot extremes have been accompanied by observed decreases in frost days over much of North America (Alexander et al., 2006; Brown *et al*., 2010b, WGI 2.6.12), decreases in cold spells over the U.S. (Kunkel *et al*., 2008, WGI 2.6.1), and increasing ratio of record high to low daily temperatures over the U.S. (Meehl *et al*., 2009). However, relative cooling has occurred over central North America and the eastern USA (e.g., Alexander et al., 2006; Peterson *et al*., 2008, WGI 2.6.1), with more pronounced contrast seen in trends over the past century than in trends over the last three decades (WGI Figure 2.22, Figure 26-3). It is possible that this “warming hole” has been influenced by changes in the hydrologic cycle (e.g., Pan *et al*., 2004; Portmann *et al*., 2009), as well as by decadal-scale variability in the ocean (e.g., Kumar *et al*., 2012; Meehl *et al*., 2012).

[INSERT FIGURE 26-3 HERE
Figure 26-3: Changes in annual temperature and precipitation. White indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model’s 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.]

WGI notes that observations show increases in heavy precipitation over Mexico, the U.S. and Canada between the mid-20th century and the early 21st century (WGI 2.6.2, DeGaetano, 2009; Peterson and Baringer, 2009; Pryor *et al*., 2009). Observational analyses of changes in drought are more equivocal over North America, with mixed sign of trend in dryness over Mexico, the U.S. and Canada (WGI 2.6.2 and Figure 2.42, Dai, 2011; Sheffield *et al*., 2012). WGI notes evidence for earlier occurrence of peak flow in snow-dominated rivers globally (Rosenzweig, 2007, WGI 2.6.2). Observed snowpack and snow-dominated runoff have been extensively studied in the western U.S. and western Canada, with observations showing primarily decreasing trends in the amount of water stored in spring snowpack from 1960-2002 (with the most prominent exception being the central and southern Sierra Nevada)

(Mote, 2006) and primarily earlier trends in the timing of peak runoff over the 1948-2000 period (Stewart *et al*., 2006). WGI also assess observed changes in extreme storms in North America, noting that observational limitations prohibit conclusions about trends in severe thunderstorms (WGI 2.6.2) and tropical cyclones (WGI 2.6.3). The most robust trends in extratropical cyclones over North America are determined to be towards more frequent and intense storms over the northern Canadian Arctic and towards less frequent and weaker storms over the southeastern and southwestern coasts of Canada over the 1953-2002 period(WGI 2.7.4, Wang *et al*., 2006).

WGI concludes that it is "*virtually certain* that globally mean sea level (GMSL) has risen at a mean rate between 1.4 to 2.0 mm yr^{-1} over the 20th Century and between 2.7 and 3.7 mm yr^{-1} since 1993." (WGI 3 Executive Summary). In addition, WGI concludes that observed changes in extreme sea level have been caused primarily by increases in mean sea level (WGI 3.7.5). WGI also concludes that regional variations in the observed rate of sea level rise can result from processes related to atmosphere and ocean variability (such as lower rates along the west coast of the U.S.) or vertical land motion (such as high rates along the U.S. Gulf Coast), but that the persistence of the observed regional patterns is unknown (WGI 3.7.3).

26.2.2.2. Climate Change Projections

Chapter 14 of the WGI contribution to the AR5 assesses processes important for regional climate change, with section 14.7.3 focused on North America. Many of the WGI conclusions are drawn from Annex I of the WGI contribution to the AR5.

The CMIP5 ensemble projects very likely annual warming over North America, with very likely increases in temperature over all land areas in the mid- and late-21st-century periods of RCP4.5 and RCP8.5 (Figure 26-4). Mean warming across climate models exceeds 2˚C over most land areas of all three countries in the mid-21st-century period of RCP8.5 and the late-21st century period of RCP4.5, and exceeds 4˚C over most land areas of all three countries in the late-21st-century period of RCP8.5. The largest mean warming occurs over the high latitudes of the United States and Canada, as well as much of eastern Canada, including greater than 6˚C of annual warming in the late-21st-century period of RCP8.5. The smallest mean warming occurs over areas of southern Mexico, the Pacific Coast of the United States, and the southeastern United States.

[INSERT FIGURE 26-4 HERE
Figure 26-4: Observed and simulated variations in past and projected future annual average precipitation and temperature over land areas of Canada, the contiguous United States, and Mexico. Black lines show several estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.]

Most land areas north of 45˚N exhibit likely increases in annual precipitation in the late-21st-century period of RCP8.5, including very likely increases over the high latitude areas of North America (Figure 26-3). In contrast, much of Mexico and the southcentral and southwestern United States exhibit likely decreases in annual precipitation in the late-21st-century period of RCP8.5. Likely changes in annual precipitation are much less common at lower levels of forcing, with few areas of Mexico exhibiting changes that exceed the baseline variability in the mid- or late-21st-century periods of RCP4.5 or the mid-21st-century period of RCP8.5. Likewise, likely changes in annual precipitation in the United States are primarily confined to increases over the northern latitudes during the mid- and late-21st-century periods of RCP4.5, and the mid-21st-century period of RCP8.5. Very likely changes in annual precipitation are confined primarily to increases over the high latitude areas of North America throughout the illustrative RCP periods, with very likely increases occurring in the mid-21st-century period of RCP4.5 and becoming generally more wide-spread at higher levels of forcing.

The CMIP5 ensemble projects warming in all seasons over North America beginning as early as the 2016-2035 period of RCP2.6, with the greatest warming occurring in winter over the high latitudes (WGI Annex I and Figure

26-4; Diffenbaugh and Giorgi, 2012). An important measure of the robustness of climate change is the magnitude of the change ("signal") relative to the background climate variability ("noise"). From the perspective of impacts, adaptation and vulnerability, the "signal-to-noise ratio" helps to quantify the magnitude of climate changes relative to the background variability to which natural and human systems are accustomed in the recent climate. The CMIP5 and CMIP3 ensembles suggests that the response of warm-season temperatures to elevated radiative forcing exhibits higher signal-to-noise ratio than the response of cold-season temperatures (Diffenbaugh and Scherer, 2011; Kumar *et al*., 2012), and the CMIP3 ensemble suggests that the response of temperature in low-latitude areas of North America exhibits higher signal-to-noise ratio than the response of temperature in high-latitude areas (Diffenbaugh and Scherer, 2011). In addition, CMIP3 and a high-resolution climate model ensemble suggest that the signal-to-noise ratio of 21st century warming is far greater over the western U.S., northern Mexico and the northeastern U.S. than over the central U.S. (Diffenbaugh *et al*., 2011).

CMIP5 projects increases in winter precipitation over Canada and Alaska, consistent with projections of poleward shift in the dominant cold-season stormtracks (WGI 14.7.3, Yin, 2005), extratropical cyclones (Trapp *et al*., 2009) and areas of moisture convergence (WG1 14.7.3), as well as with projections of shift towards positive North Atlantic Oscillation (NAO) trends (WGI 14.7.3, Hori *et al*., 2007). CMIP5 also projects decreases in winter precipitation over the southwestern U.S. and much of Mexico associated with the poleward shift in the dominant stormtracks and the expansion of subtropical arid regions (WGI14.7.3, Seager and Vecchi, 2010b). However, there are uncertainties in hydroclimatic change in western North America associated with the response of the tropical Pacific sea surface temperatures (SSTs) to elevated radiative forcing (particularly given the influence of tropical SSTs on the Pacific North American pattern (PNA) and north Pacific storm tracks) (WGI 14.7.3, Cayan *et al*., 1999; Findell and Delworth, 2010; Seager and Vecchi, 2010a), and not all CMIP5 models simulate the observed recent hydrologic trends in the region (Kumar *et al*., 2012)

Mexico and the western U.S. emerge as prominent areas of aggregate climate change in both RCP4.5 and RCP8.5, primarily as result of extreme heat in all seasons and extreme dry conditions in winter and spring (Diffenbaugh and Giorgi, 2012). CMIP5 projects substantial increases in the occurrence of extremely hot seasons over North America in early, middle and late 21st century periods of RCP8.5, including greater than 80% of summers exceeding the late 20th century maximum during the 2070-2099 period (Diffenbaugh and Giorgi, 2012). The CMIP5 ensemble also projects substantial decreases in snow accumulation over the U.S. and Canada, including greater than 80% of years with March snow amount below the late 20th century median – and greater than 30% of years below the late 20th century minimum – over much of the western U.S. and western Canada beginning the middle 21st century period of RCP8.5 (Diffenbaugh *et al*., 2012). These decreases in spring snow amount are associated with substantial changes in the timing of total surface runoff, including greater than 30% of years above (below) the baseline winter (spring) runoff over the high elevation areas of the western U.S. and western Canada during the 2070-2099 period, greater than 50% of years below the summer maximum runoff over the high elevations of northwestern Canada, and greater than 30% of years above the baseline winter maximum runoff over most of central Canada during the 2070-2099 period (Diffenbaugh *et al*., submitted) .

26.3. Water Resources and Management

26.3.1. Observed Impacts on Water Resources

Drought: Although no evidence has yet been found indicating trends of increased drought occurrence at the North American continental scale (section 26.2.2.1.1., USCCSP, 2008), local trends over the past approximately 40 years have been observed in east and southwest USA, north and northwest Mexico, and the Canadian Prairies (Barnett *et al*., 2008; Groisman and Knight, 2008; Ellis *et al*., 2010; SEMARNAT-INECC, 2012, section 26).

Floods: Changes in the magnitude or frequency of flood events are difficult to attribute to climate change. Floods are generated by multiple mechanisms affected by numerous influences such as land use change, urbanization and flow regulation (section 26.2.2.1, Villarini *et al*., 2011; SEMARNAT-INECC, 2012). For instance, in the eastern USA, the relationship between heavy rainfall and flooding shows a large annual variability that is not easily associated with changing climate (Smith *et al*., 2011).

Mean Annual Streamflow: While annual precipitation and runoff increases have been found in the Midwestern and Northwestern United States, decreases have been observed in southern states (Georgakakos *et al*., 2013).

26.3.2. Water Use

Water withdrawals are already exceeding stressful levels (exceeding 40 percent of supply) in many regions of North America such as the southwest US, northern and central Mexico (particularly Mexico City), southern Ontario and the southern Canadian Prairies (National Water Commission of Mexico, 2010; Romero-Lankao, 2010; Sosa-Rodriguez, 2010; Averyt *et al*., 2011; Environment Canada, 2013a).

10 % to 30 % of the water quality monitoring sites in Mexico have polluted or heavily polluted water, depending upon the parameter monitored (National Water Commission of Mexico, 2010), and about 44% of assessed stream miles, and 64% of assessed lake areas in the US were not clean enough to support uses such as fishing and swimming (U.S. EPA, 2004). Conversely the stations in Canada's 16 most populated drainage basins reported at least fair quality, with many basins reporting good or excellent quality (Environment Canada, 2013b).

As noted in Section 26.7, the water resources management infrastructure in most areas of North America is in need of repair, replacement or expansion.

26.3.3. Projected Impacts and Risks

26.3.3.1. Water Supply

Most of the discussion focuses on surface water as there are few groundwater studies (Tremblay *et al*., 2011; Georgakakos *et al*., 2013).

In arid and semi-arid western USA and Canada and in most of Mexico, except the southern tropical area, water supplies are predicted to be further stressed by climate change (IMTA, 2010; MacDonald, 2010b; Montero Martinez *et al*., 2010), with expected changes varying based upon climate models, time frames and regions studied. For instance, along the United States-Mexico border under A2, A1B, and B1 scenarios for 2050 and 2080s, reduced water availability is anticipated to result from increasing temperatures and high degree of annual precipitation variability (Cayan *et al*., 2010; IMTA, 2010), resulting in possible surface and groundwater overexploitation (CONAGUA, 2011). Similarly, with scenarios A2 and A1B in 2039, the northeastern coast of Mexico will probably face high water stress due to the decreased availability and increased demand for water leading to overexploitation of groundwater even though the region already has many reservoirs (CONAGUA, 2011). Compounding factors will include salt water intrusion, and increased groundwater and surface water pollution (Leal *et al*., 2008).

In the US southwest and southeast, ecosystems and irrigation are projected to be particularly stressed by decreases in water availability and growing water demand, or by water transfers to urban and industrial users with greater economic productivity (Seager *et al*., 2009; Georgakakos *et al*., 2013) . In the Colorado River Basin crop irrigation requirements for pasture grass are projected to increase by 20% by 2040 and by 31 % by 2070 (AECOM, 2010). In the Rio Grande basin, New Mexico, runoff is projected to be reduced by nearly 30% by 2080. Water transfers entail significant transaction costs associated with adjudication and potential litigation. In addition, transferring water reduces ecological, environmental, social, and cultural attributes (Hurd and Coonrod, 2012).

Other parts of North America are projected to have different climate risks. For instance, while no vulnerability of water resources is projected for 2050 over the tropical southern region of Mexico, greater precipitation is projected after 2050, increasing the possibility of destroying hydropower and water storage dams by floods (IMTA, 2010). Throughout the 21st century, the cities of Seattle, Everett, and Tacoma, Washington, are projected to have drawdown of average seasonal reservoir storage in the absence of demand reduction because of less snowpack even though annual streamflows increase. Without accounting for demand increases, reliability of all systems can remain above 98% for Seattle, Everett and Tacoma through mid and late century (Vano *et al*., 2010a). Throughout eastern USA, water supply systems will be negatively impacted if groundwater recharge lessens and snowpack storage is lost as well as by rising sea levels, increased storm intensities, salt water intrusion, lower flows, land use, population changes, and other stresses (Sun *et al*., 2008; Obeysekera *et al*., 2011). Southern Alberta, where approximately two-thirds of Canadian irrigated land is found (Poirier and de Loë, 2012) is projected to experience declines in mean annual streamflow, especially during the summer (Shepherd *et al*., 2010.). Decreases of 5% annual average runoff of the Chaudière River watershed, in Québec, Canada, were simulated for 2010-2039 relative to the reference period 1970-1999 using a variety of downscaling methods (Quilbe *et al*., 2008; Chen *et al*., 2011).

26.3.3.2. Water Quality

Reduced flow conditions can result in quality impacts due to increased temperature, increased concentrations of dissolved substances, and dissolved oxygen level changes (Novotny and Stefan, 2007; Delpla *et al*., 2009.; Daley *et al*., 2009; Benotti *et al*., 2010). Increased wildfires linked to a warming climate are expected to affect water quality downstream of forested headwater regions (Emelko *et al*., 2011). Model simulation of lakes under a range of plausible higher air temperatures (Tahoe, Great Lakes, Lake Onondaga and shallow polymictic lakes), depending on the system, predict a range of impacts such as increased phytoplankton, fish and cyanobacteria biomass, lengthened stratification periods with risks of significant hypolimnetic oxygen deficits in late summer with solubilization of accumulated phosphorous and heavy metals with accelerated reaction rates, and decreased lake clarity (Dupuis and Hann, 2009.; Trumpickas *et al*., 2009; Sahoo *et al*., 2010; Taner *et al*., 2011). Model simulations have found seasonal climate change impacts on nonpoint source pollution loads, while others have found no impact (Marshall and Randhir, 2008; Tu, 2009; Praskievicz and Chang, 2011; Taner *et al*., 2011). Tu (2009), Praskievicz and Chang (2011), Daley et al (2009), Tong et al (2012), and Wilson and Weng (2011) find the combined impacts of climate change and development will result in poorer water quality. However, where investigated, climate change impacts were greater than those of land use changes.

Delpla (2009), Carriere et al. (2010), and Emelko (2011) found that changes in physical-chemical-biological parameters and micropollutants will negatively affect drinking water treatment and distribution systems. Wastewater treatment plants will be more vulnerable as increases in rainfall and wet weather lead to higher rates of inflow and infiltration (King County Department of Natural Resources and Parks, 2008; NYCDEP., 2008; Flood and Cahoon, 2011). These plants will also face reduced hydraulic capacities due to higher sea levels and increased river and coastal flooding (Flood and Cahoon, 2011), with higher sea levels also threatening the sewage collection systems (Rosenzweig *et al*., 2007; King County Department of Natural Resources and Parks, 2008)

26.3.3.3. Flooding

Projected increases in flooding (Georgakakos *et al*., 2013) may affect sectors ranging from agriculture and livestock in southern tropical Mexico (National Water Commission of Mexico, 2010) to urban and water infrastructure in areas such as Dayton, Ohio, metro Boston and the Californian Bay-Delta region (National Research Council, 1995; Kirshen *et al*., 2006; California Department of Water Resources, 2009; Wu, 2010). Floods could begin earlier, have earlier peaks and longer durations (e.g., southern Quebec basin . Urbanization can compound the impacts of increased flooding due to climate change, particularly in the absence of flood management infrastructures that take climate change into account (Hejazi and Markus, 2009; Mailhot and Duchesne, 2010; Ntelekos *et al*., 2010; Sosa-Rodriguez, 2010) estimate that annual riverine flood losses in the USA could increase from approximately $2 billion now to $7-$19 billion annually by 2100 under the business as usual scenario.

26.3.3.4. Instream Uses

Projections of climate impacts on instream uses vary by region and time-frame. Hydropower generation, affected by reduced lake levels, is projected to decrease in arid and semi-arid areas of Mexico (SEMARNAT, 2009; Sosa-Rodriguez, 2013) and in the Great Lakes (Buttle *et al*., 2004; Mortsch *et al*., 2006; Georgakakos *et al*., 2013). In the

US Pacific Northwest it is projected to increase in 2040 by 5% in the winter and decrease by 13% in the summer, with annual reductions of about 2.5%. Larger decreases of 17% to 21% in summer hydropower production are projected by 2080 (Hamlet *et al.*, 2010). On the Peribonka River system in Quebec, annual mean hydropower production would decrease by 1.8% for 2010-2039 and increase by 9.3% and 18.3% respectively during the periods 2040-2069 and 2070-2099 (Minville *et al.*, 2009). Navigation on the Great Lakes, Mississippi River and other inland waterways may benefit from less ice cover but will be hindered by increased floods and droughts (Georgakakos *et al.*, 2013).

26.3.3.5. Energy-Water Nexus

Energy demands for water supply and wastewater treatment are projected to increase under climate change due to increases in pumping and treatment requirements, partly due to increased surface water temperatures (CH2M Hill, 2009; Skaggs *et al.*, 2012). Cooling of USA thermoelectric power plants is predicted to be affected; it accounts for approximately 50% of the nation's water withdrawals (Kenny *et al.*, 2009). The vulnerability of these power plants will vary regionally depending on differences in water availability and temperature due to climate impacts (Wilbanks *et al.*, 2008). Carbon pricing policies may decrease thermoelectric power plant freshwater withdrawals and consumption in the continental USA compared to business as usual policies (Chandel *et al.*, 2011). Total freshwater consumption for national energy production (including thermoelectric power, biofuels, and fossil fuels) in the United States is estimated at 11% (Elcock, 2010; Mekonnen and Hoekstra, 2011; Spang *et al.*, 2013). However, energy production mitigation measures such as carbon capture, nuclear power, and some biofuels will exacerbate stresses on water supplies and quality (Engelhaupt, 2007; Delucchi, 2010; Stone *et al.*, 2010; Powers *et al.*, 2011; Cooper and Sehlke, 2012)

26.3.4. Adaptations

Most of the project-level adaptation actions are no-regret policies. For instance, in preparation for more intense storms, New York City is using green infrastructure to capture rainwater before it can flood the combined sewer system and is elevating boilers and other equipment above ground (Bloomberg, 2012). The Mexican cities of Monterrey, Guadalajara, Mexico City and Tlaxcala are reducing leaks from water systems (SEMARNAT, 2009; National Water Commission of Mexico, 2010; Romero-Lankao, 2010; Sosa-Rodriguez, 2010). Regina, SK has increased urban water conservation efforts (Lemmen *et al.*, 2008).

The 540-foot high, 1300-foot long concrete Ross Dam in the state of Washington, USA was built on a special foundation so it could later be raised in height (Jay Lund, personal communication). Dock owners in the Trent-Severn Waterway in the Great Lakes have moved their docks into deeper water to better manage impacts on shorelines (Coleman *et al.*, 2013). The South Florida Water Management District is assessing the vulnerability to sea level rise of its aging coastal flood control system and exploring adaptation strategies, including a strategy known as forward pumping (Obeysekera *et al.*, 2011). In Cambridge, Ontario, extra capacity culverts are being installed in anticipation of larger runoff (Scheckenberger *et al.*, 2009).

Water meters have been installed to reduce water consumption by different users such as Mexican (also installing drip irrigation) and Canadian farmers and several Canadian cities (INE (National Institute of Ecology), 2006; Lemmen *et al.*, 2008). Agreements and regulations are underway, such as the "shortage sharing agreement" signed in 2007 for the management of the Colorado River, USA and driven by concerns about water conservation, shortage planning, better reservoir coordination, and preserving flexibility to respond to climate change (http://www.usbr.gov/lc/region/programs/strategies.html, accessed January 27, 2013). Quebec Province is also requiring dam safety inspections each 10 years to also account for new knowledge on climate change impacts (http://www.cehq.gouv.qc.ca/loisreglements/barrages/reglement/index-en.htm).

26.4. Ecosystems and Biodiversity

Recent research has documented gradual changes in physiology, phenology and distributions in North American ecosystems (Dumais and Prévost, 2007). Concomitant with 20th century temperature increases, shifts in plant, mammal, bird, lizard, and insect species' distributions have been documented extensively in the western United States and eastern Mexico (Parmesan, 2006; Kelly and Goulden, 2008; Moritz *et al*., 2009; Tingley *et al*., 2009; Sinervo *et al*., 2010). These gradual climate-induced distribution shifts interact with other existing environmental changes such as land-use change, hindering the ability of species to respond.

Different techniques have been applied to assess the vulnerability of North American ecosystems to changes in climate (Loarie *et al*., 2009). A global risk analysis based on dynamic global vegetation models identified boreal forest in Canada as notably vulnerable to ecosystem shift(Scholze *et al*., 2006). Building upon results presented in the AR4, studies have identified a more prominent role of extreme events such as droughts and floods on vegetation mortality, increased infestation by fungi, sea levels rise, hurricanes and other increasingly severe impacts facing North American ecosystems (Chambers *et al*., 2007; IPCC, 2012). Although North American forests were a net carbon sink between 1990-2007 (Pan *et al*., 2011), current measurements suggest a reduction in the global net primary production of 0.55 petagrams of carbon due to large-scale droughts between 2000 to 2009 (Zhao and Running, 2010).

Climatic changes are expected to affect North American terrestrial and coastal ecosystems in significant and in many cases adverse ways. The responses of biological systems depend on organizational level and can differ across communities, populations or species. Changes in temperature, precipitation amount, carbon dioxide concentrations can have differential effects across species and ecological communities (Parmesan, 2006; Matthews *et al*., 2011). Risk studies on 134 species in U.S. and 16 forest species in Mexico estimated shifts in potential habitat under climate scenarios (Iverson *et al*., 2008; Gómez *et al*., 2011; Iverson *et al*., 2012). These studies have contributed to planning management strategies for adaptation of these ecosystems (USDA Forest Service, 2010; Leichenko, 2011; Comisión Intersecretarial de Cambio Climático, 2012).

The following section focuses in more depth on climate vulnerabilities in forests and coastal ecosystems and transboundary ecosystems across all three North American countries where research advances since AR4 justify further exploration. Additional synthesis on climate impacts on ecosystems in general and terrestrial, coastal and ocean in particular can be found in Chapter 8 of the (Groffman *et al*., 2013) and chapters 4, 5 and 6 of AR5.

26.4.1. Tree Mortality and Forest Infestation

26.4.1.1. Observed Impacts

Droughts of unusual severity, extent, and duration have affected large parts of western and southwestern North America and resulted in regional-scale forest dieback in Canada, US and Mexico. Extensive tree mortality has been related to exacerbated drought by higher summertime temperatures mainly in quaking aspen (*Populus tremuloides*), pinyon pine (*Pinus edulis*) and lodgepole pine (*Pinus contorta*) (Breshears *et al*., 2005; Hogg *et al*., 2008; Raffa *et al*., 2008; Worral *et al*., 2008; Michaelian *et al*., 2011; Anderegg *et al*., 2012). Similarly, in 2011 and 2012 oak forest dieback in Northern and central Mexico was associated with extreme temperatures and severe droughts (Conafor, 2012).Widespread forest-mortality events triggered by extreme climate events can alter ecosystem structure, function, and severely impact biodiversity (Phillips *et al*., 2009; Allen *et al*., 2010; Anderegg *et al*., 2013). Similarly, multi-decadal changes in demographic rates, particularly mortality, indicate climate-mediated changes in forest communities over longer periods (Hogg and Bernier, 2005; Williamson *et al*., 2009a). Increases in the average mortality rate of 4.7% yr^{-1} between 1963 and 2008 were reported for Canada's boreal forests (Peng *et al*., 2011), and in western US forests as well (van Mantgem *et al*., 2009).

The influences of climate change on ecosystem disturbance, such as insect outbreaks have become increasingly salient and suggest that these disturbances could have a major influence on North American ecosystems and economy in a changing climate. In terms of carbon stores these outbreaks can turn forests into carbon sources (Kurz *et al*., 2008a; Kurz *et al*., 2008b; Hicke *et al*., 2012).

Warm winters in Western Canada and U.S. have allowed the larvae of mountain pine beetle to overwinter, causing the "largest and most severe [outbreak] in history" from Alaska to Colorado (Bentz, 2008), with massive die-offs in some regions. An estimated 18,177 km2 of U.S. forests is affected (Williams *et al*., 2010). British Columbia, Canada had the largest impact (Brown *et al*., 2010a), with mortality in over 7 million hectares (Aukema *et al*., 2006).

26.4.1.2. Projected Impacts and Risks

Projected increases in drought severity in southwestern United States and northwestern Mexico suggest that these ecosystems may be more vulnerable to rapid changes, such as vegetation mortality (Seager *et al*., 2007; Overpeck and Udall, 2010; Williams *et al*., 2010), and an increase of biological agents such as beetles, borers, pathogenic fungi, budworms and other pests (Drake *et al*., 2005). An index of forest drought stress calibrated on tree rings indicates that projected drought stress by the 2050s will exceed the most severe droughts of the past 1,000 years (Park Williams *et al*., 2013).

Major changes are projected towards the end of the century in forest soils in southern Quebec in 2040-2069 and 2070-2099 projected with subsequent decrease between 20-40% in the growing season of trees due to elevated evapotranspiration rates (Houle *et al*., 2012). More frequent droughts in tropical forests may change forest structure and regional distribution, favoring a higher prevalence of deciduous species in the forests of Mexico (Drake *et al*., 2005; Trejo *et al*., 2011).

Shifts in climate are expected to lead to changes in forest infestation, including expansion into higher latitudes and elevations (Bentz *et al*., 2010). Predicted climate warming is expected to have effects on bark beetle population dynamics in the southwestern United States and Northern part of Mexico that may include increases in developmental rates, generations per year, and changes in habitat suitability (Waring *et al*., 2009). As a result, the impacts of *Dendroctonus frontalis* and *Dendroctonus mexicanus* on forest resources are likely subject to amplification (Waring *et al*., 2009).

26.4.2. Coastal Ecosystems

Highly productive estuaries, wetlands and mangrove ecosystems are present in the East and West coasts of North America. These fragile ecosystems are vulnerable to sea level rise, increase in sea surface temperature, acidification of water, and hurricanes. Coastal zones are subject to many other stressors as well, including urban and tourist developments and the indirect effects of overfishing *(*Bhatti, 2006); (Mortsch *et al*., 2006; CONABIO-CONANP-TNC-PRONATURA, 2007; Lund *et al*., 2007)

26.4.2.1. Observed Impacts

Sea level rise, which has not been uniform across the coasts of North America (Crawford *et al*., 2007; Kemp *et al*., 2008; Leonard *et al*., 2009; Zavala-Hidalgo *et al*., 2010; Sallenger *et al*., 2012), is directly related to flooding and loss of coastal dunes, oyster beds, seagrass and mangroves affectations (Feagin *et al*., 2005; Cooper *et al*., 2008; Najjar *et al*., 2010; Martinez Arroyo *et al*., 2011; McKee, 2011). Influenced by rising sea levels, severe flooding and salinity movement inward in deltas have been detected in Sacramento-San Joaquin area, which can severely alter vegetation and species habitat (Lund *et al*., 2007).

Increases in sea surface temperature in estuaries threaten species, especially cold water fish and the metabolism of many organisms (Crawford *et al*., 2007). Historical warm periods have coincided with low salmon abundance and restriction of fisheries in Alaska (Crozier *et al*., 2008; USGCRP, 2009). In addition, some fisheries currently support sardine fishing where they once fished for anchovy (Chavez *et al*., 2003). North Atlantic mammals, and tropical coral reefs in the Gulf of California, and the Caribbean are affected by increase in transmission diseases associated with warming of waters and low water quality(ICES, 2011; Mumby *et al*., 2011).

There is *very high confidence* about acidification in oceans and coasts (Box CC-OA). The increased CO2 contributes to acidification and affects mainly calcareous organisms colonial mussel beds temperate coastal and indirectly influences food webs of benthic species (Wootton *et al*., 2008). The acidity in conjunction with high temperatures have been identified as a serious threat to coral reefs and other marine ecosystems (Doney *et al*., 2009; Hernández *et al*., 2010; Mumby *et al*., 2011).

The ecological effects of tropical storms and hurricanes can alter coastal wetland hydrology, geomorphology (erosion), biotic structure in reefs and nutrient cycling. Hurricanes impacts on the coastline change dramatically the marine habitat of sea turtles reducing feeding habitats, like coral reefs, areas of seaweed and nesting places. (Liceaga-Correa *et al*., 2010; Márquez, R. and Jiménez, Ma. del C., 2010).

26.4.2.2. Projected Impacts and Risks

Projected increases in sea levels, particularly along the coastlines of Florida, Louisiana, North Carolina, and Texas(Kemp *et al*., 2008; Leonard *et al*., 2009; Weiss *et al*., 2011a), are projected to reduce flood tolerance of many plants in coastal ecosystems and their recovery almost impossible; result in a loss of wetlands and mangroves of between 20% (in Tamaulipas) to 94% (in Veracruz) for the Gulf of Mexico coast by the end of the 21^{st} century (Flores Verdugo *et al*., 2010); and lead to large losses in tidal marshes in San Francisco Bay (Stralberg *et al*., 2011).

Projected impacts of increased water temperatures include contraction of coldwater fish habitat and expansion of warm-water fish habitat, which can increase the presence of invasive species threatening resident populations (Janetos *et al*., 2008). Up to 40 % of Northwest salmon populations may be lost by 2050 due to climate change (Battin *et al*., 2007; Crozier *et al*., 2008). Future restrictions are expected in productivity and abundance at the southern end while doing the opposite at the northern end of their range (Azumaya *et al*., 2007).

The progressive onset of ocean acidification will cause damage and reduction of coral growth with consequent extinctions and declines in biodiversity (Veron *et al*., 2009). Increases of CO2 alter calcification of bivalve and other organisms with shells, oyster larvae reared with levels between 560 to 480ppm were held in Chesapeake Bay and found slower calcification than in the current environmental conditions (Najjar *et al*., 2010).

The projected increase in the frequency of category 4 and 5 storms by the end of the 21st century (Bender *et al*., 2010; Knutson *et al*., 2010) might directly affect the mangroves over a period of at least 25 years and completely change their structure and age (Kovacs *et al*., 2004).

26.4.3. Ecosystems Resilience, Adaptation, and Mitigation

The resilience of the ecosystems to climate change depends on different and context specific factors: the biodiversity and conservation of habitats and food chains (Thompson *et al*., 2010) the interactions between relatively rapid rate of climate change and the land-use changes that can reduce species capacity to adapt or to be resilient (Bhatti et al 2006); (Magrin *et al*., 2007). The uncertain implications of these changes on productivity of fisheries and forestry (ICES, 2011; Okey *et al*., 2012) can force rural and indigenous population (whose economies depend on this resources) to migrate (Perry *et al*., 2010, section 26.6).

Some adaptation measures have been implemented to respond to climate change impacts on ecosystems: increases in plant community composition and biological diversity to reduce Canadian forest infestations (Johnston *et al*., 2010); breeding programs for resistance to diseases and insect pests (Yanchuk and Allard, 2009); selection by forest or fisheries managers of productive activities that are more adapted to new climatic conditions (chapter 4 Canadian Assessment); effective planning and regulations on other human activities such as commercial fishing and mass tourism(Pratchett *et al*., 2008); for wetlands in the Great Lakes, Canada and coastal areas in San Joaquin and San Francisco, California, enforcement mechanisms for using water regulation technologies and maintain quantity and quality of water bodies (Mortsch *et al*., 2006; Okey *et al*., 2012).Human-assisted migration has been proposed as a potential management option to maintain optimal health and productivity of forests; yet the technique has logistical and feasibility challenges (Keel, 2007; Winder *et al*., 2011).

Adaptation research suggests that improving climate resilience and adaptation requires changes in the approach to protected area planning, establishment and management (CONABIO-CONANP-TNC-PRONATURA, 2007; March *et al*., 2011), and that it will be much more difficult and, in some cases, not sufficient if global temperature rise exceeds 2ºC above preindustrial levels (Mansourian *et al*., 2009). One of the more notable short-term changes in the policy arena is the discussion of GHG emissions reduction through CDM and REDD+ and management, conservation and restoration of forest carbon stocks. There are manifold ways through which forests influence the climate both biogeochemically (e.g. carbon sequestration) and biophysically (e.g. albedo and roughness)(Anderson and Bell, 2009; Anderson *et al*., 2011). Managers face challenges in adjusting management practices in favor of carbon accumulation, while at the same time maintaining biodiversity, recognizing the rights of indigenous people and contributing to local economic development (FAO, 2012).

_____ START BOX 26-2 HERE _____

Box 26-2. Wildfires

North America's large wildfire activity has markedly increased since the mid-1980s, and large wildfires have occurred with increased frequency and durations, within longer wildfire seasons (Westerling *et al*., 2006; Williamson *et al*., 2009b). The great conflagrations that have occurred in western Canada, the U.S. and Mexico in recent years are related to long and warm spring and summer droughts in those years, particularly when they have been, accompanied by wind events. (Holden *et al*., 2007; CONAFOR, 2011). Legacies of forest management also play a substantial role in wildfire risk across systems.

Socio-Ecological Impacts

Although fire-adapted ecosystems exist, increasing summer wildfires could lead to changes in dominant vegetation types and community structure. In places like Sierra Nevada, mixed conifer forests, which have a natural cycle of small, non-crown fires, will have an increased likelihood of massive crown-fires. Human use of fires in forests not prone to fires, such as tropical forests can have devastating impacts, and is strongly related to the frequency of fires (Bond and Keeley, 2005; CONANP and TNC, 2009).

While healthy forests provide carbon sequestration that benefits climate change mitigation, forests affected by pests and fires are less effective carbon sinks, and wildfires themselves are a source of emissions. Furthermore, fires pose a direct threat to human lives, property and health. The expansion of human habitation or productive activities in peri-urban areas or near forested areas, alongside legacies of forest management, has undoubtedly increased the probability of ignitions, causing severe fires and increasing human exposure (Radeloff *et al*., 2005; Peter *et al*., 2006; Fischlin *et al*., 2007; Theobald and Romme, 2007; Gude *et al*., 2008; Hammer *et al*., 2009). Wildfires pose direct health threats as well. According to the EM-DAT disaster database, over the last 30 years, 155 people were killed in wildfires across North America, including 103 in the United States, 50 in Mexico and 2 in Canada (CRED, 2012). Direct effects include injury and respiratory effects from smoke inhalation, with firefighters at increased risk (Naeher *et al*., 2007; Reisen and Brown, 2009; Reisen *et al*., 2011). Contingent on shifting fire regime, there is *high confidence* that wildfire activity will cause health impacts at the individual and neighborhood levels.

Climate Variability and Extremes

Drought conditions are strongly associated with wildfire occurrence, as dead fuels such as needles and dried stems promote the incidence of firebrands and spot fires (Keeley and Zedler, 2009) (Liu, et al.2012). Drought periods in Alberta and Idaho coincide with large burned areas (Pierce and Meyer, 2008; Kulshreshtha, 2011). Decadal climatic oscillations also contribute to drought conditions, and thus to wildfires. The areas burned in the North American boreal forest and in northwest and central Mexico are strongly related to the dynamics of these large-scale climatic patterns (Macias Fauria and Johnson, 2006; Skinner *et al*., 2006; Villers-Ruíz and Hernández-Lozano, 2007; Macias

Fauria and Johnson, 2008), which are already shifting toward hotter temperatures and longer droughts with the advance of climate change.

Southern and western Canada, Alaska and Mexico have all experienced a trend toward drier conditions since the 1950s (Kunkel *et al.*, 2008), and augmented drought conditions are projected for a large proportion of the Western interior, Florida, and Mexico by 2100. Drought index projections and climate change regional models carried out in the USA show increases in the potential for fires, mainly in summer and fall, on the southeast Pacific coast, Northern Plains and the Rocky Mountains (Liu, et al 2012).

Adaptation Strategies

Further research on the relationships between climate and wildfire should include attention to population growth, land-use planning and forest structure as important aspects for adaptation planning. Prescribed fire may be an important tool for managing fire risk in Canada and the US (Hurteau and North, 2010; Wiedinmyer and Hurteau, 2010; Hurteau *et al.*, 2011). Managers in the U.S. have encouraged reduction of flammable vegetation around structures with some success (Stewart *et al.*, 2006). However, such efforts depend largely on the socio-economic capacity of communities at risk, the extent of resource dependence, community composition, and the risk perceptions, attitudes and beliefs of decision-makers, private property owners, and the public (McFarlane, 2006; Repetto, 2008; Collins and Bolin, 2009; Martin *et al.*, 2009; Trainor *et al.*, 2009; Brenkert-Smith, 2010).

Forest management also requires stakeholder involvement and investment. The provision of adequate information on smoke, managed fire/fire-use, pest management, and forest thinning is crucial, as is building trust between stakeholders and land managers (Dombeck *et al.*, 2004; Flint *et al.*, 2008; Chang *et al.*, 2009). However, institutional shifts from reliance on historical records toward incorporation of climate forecasting in forest management will also be crucial to developing resilience in these areas (McKenzie *et al.*, 2004; Millar *et al.*, 2007; Kolden and Brown, 2010).

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26.5. Agriculture and Food Security

Climate change is projected to cause food price increases and declines in caloric availability globally (Nelson *et al.*, 2009); and changes in supply and price from diversion of production into biofuels (Searchinger *et al.*, 2008; Valero-Gil and Valero, 2008; Liverman and Kapadia, 2010). Canada and the U.S. are relatively food secure, although households living in poverty and unengaged in food production are vulnerable. Mexico has high levels of food insecurity, where food constitutes a higher proportion of household budget (Juarez and Gonzalez, 2010). Indigenous peoples are also sensitive. Because North America is a major exporter (FAO, 2009; Schlenker and Roberts, 2009), shifts in agricultural productivity here may have implications for global food security.

26.5.1. Observed Impacts

There is strong evidence of the climate sensitivity of North American agricultural productivity. Historic increases in crop yield are attributed in part to increasing temperatures in Canada and high precipitation in the U.S. (Pearson *et al.*, 2008; Nadler and Bullock, 2011; Sakurai *et al.*, 2011), but optimum temperature ranges are narrow for many crops, and in many cases have already been reached (Hatfield *et al.*, 2008). Yields of grains, forage, livestock and dairy decline significantly above temperature thresholds (Wolfe *et al.*, 2008; Schlenker and Roberts, 2009; Craine *et al.*, 2010). Increasing temperatures unless accompanied by increased precipitation result in soil organic content declines (Smith *et al.*, 2009; Lin and Zhang, 2012), and increases in salinity (Sabo *et al.*, 2010). Climate change affects product quality as well (e.g. coffee (Lin, 2007), wine grapes (Hayhoe *et al.*, 2004; Jones *et al.*, 2005), wheat (Porter and Semenov, 2005), fruits and nuts (Lobell *et al.*, 2006), and cattle forage (Craine *et al.*, 2010).

Yield variances over time have been attributed to climate variability (Cabas *et al.*, 2010) (Almaraz et al 2008). Events such as drought, extreme heat and storms have also had a notable negative effect on economic returns (Chen and McCarl, 2009; Costello *et al.*, 2009) (Swanson, Hiley and Venema 2007), particularly in Mexico, where the agricultural sector accounted for 80% of weather-related financial losses over the past 20 years (Saldaña-Zorrilla, 2008).

26.5.2. Projected Impacts

Studies project productivity gains in northern regions and where water is not projected to be a limiting factor, due to longer and warmer growing seasons (Hatfield *et al.*, 2008; Pearson *et al.*, 2008; Costello *et al.*, 2009; Wheaton *et al.*, 2010; Nadler and Bullock, 2011). Overall, net declines in yields of major crops in North America are projected without adaptation, particularly for grains and perennials, although certain regions and crops may experience gains in the absence of extreme events, and projected yields vary widely by climate model (e.g., Paudel and Hatch, 2012). Yield declines combined with increased production costs would affect the economic health of the industry as well as food prices (Kiely *et al.*, 2005), although the effects on profitability are difficult to forecast, and can be expected to be nonlinear. Aggregate profits have been projected to decline by up to 58% by 2099 (CCSM, A2) (Deschenes and Kolstad, 2011) in California's agriculture industry. In northwest Montana, Net Farm Income and average returns per acre are projected to decline by 57% and 24% respectively by 2050 (A1B, B1, A2, CMIP3) (Prato *et al.*, 2010).

Among studies projecting yield declines, two factors stand out: exceedance of temperature thresholds and water availability. Projected temperature increases may affect yield negatively as early as 2020, with a growing number of studies indicating sharp declines in several major crops by 2099 (e.g., Schlenker and Roberts, 2009) (Hadley III) (Figure 26-5), and increased inter-annual variability over the next century (Sakurai *et al.*, 2011; Urban *et al.*, 2012). Projected temperature increases in California would result in declines in wine grape yields, where current conditions are already at temperature optimums (Jones *et al.*, 2005), cotton and sunflower, (A2,B1, DAYCENT model) (Lee, de Gryze and Six 2009), and nut-bearing trees (Lobell *et al.*, 2006). Even in northern regions, such as Quebec, projected temperature increases are higher than optimum for some major crops (Brassard and Singh, 2008) and result in productivity declines for fruit-bearing trees (Wolfe *et al.*, 2008).

[INSERT FIGURE 26-5 HERE
Figure 26-5 Nonlinear relation between temperature and yields. Source: Schlenker, 2009.]

The effect of temperature on yield is moderated by changes in precipitation, projections of which are more variable by region, time frame, and climate model. Increases in precipitation would off-set but not necessarily entirely compensate for temperature-related declines in productivity (Kucharik and Serbin 2008). In regions projected to experience increasing temperatures combined with declining precipitation, declines in yield and quality are more acute (Craine *et al.*, 2010; Monterroso Rivas *et al.*, 2011a). The direct effects of increasing average temperatures on livestock stress, combined with reduced forage quality, would reduce significantly milk production and weight gain in cattle (Wolfe *et al.*, 2008; Hernandez *et al.*, 2011).

Agriculture is likely to be affected by soil moisture deficits and declining water availability in the U.S. Western/Southwest, the Western Prairies in Canada, and central and northern Mexico (Pearson *et al.*, 2008; Cai *et al.*, 2009; USGCRP, 2009; Esqueda *et al.*, 2010; Vano *et al.*, 2010b; Kulshreshtha, 2011). Current sectoral competition for limited water supplies is likely to become more intense (USGCRP, 2009; MacDonald, 2010a; Vano *et al.*, 2010a; Lal *et al.*, 2011). In the western U.S. and Canadian Prairies, projected earlier Spring snowmelt and higher proportions of precipitation falling as rain would negatively affect agricultural productivity regardless of precipitation levels, as water availability in Summer and Fall are reduced (Forbes *et al.*, 2011); (Schlenker *et al.*, 2007)(Kienzle et al 2011).

Projected increases in extreme heat, drought andstorms are other factors with negative effects on productivity (Chen and McCarl, 2009; Kulshreshtha, 2011), even in regions in which beneficial impacts in response to projected changes in average conditions are anticipated (Sushama *et al.*, 2010). Projected changes in temperature and precipitation would also affect the prevalence and variety of pests, fungi and diseases (Wolfe *et al.*, 2008; Jackson *et al.*, 2009); (Wu et al 2011). Weeds are generally more responsive to increasing temperatures and CO_2 fertilization than crops (USGCRP, 2009), and the variety of weeds prevalent for a particular region is projected to change (McDonald *et al.*, 2009). Organic producers would be particularly affected (Jackson and Wheeler 2010).

Responsiveness to CO_2 varies by crop, and positive growth response ceases when plants reach a CO_2 saturation point; thus CO_2 fertilization may not compensate for the negative impacts of temperature rise (Hatfield et al 2011). Elevated CO_2 can result in reduced nitrogen and protein content in grains and forage grasses (Brassard and Singh, 2008; Karl *et al*., 2009), and weeds are more responsive to CO_2 than crop species (Wolfe *et al*., 2008; USGCRP, 2009).

A Closer Look at Mexico

While agriculture in Canada and the U.S. is largely commercial, in Mexico it is comprised primarily of subsistence farmers (2.1 million) (Claridades Agropecuarias 2006). The negative effects to productivity of projected changes in climate here may be particularly acute, in part because a large proportion of Mexico's landbase is already marginal for two of the country's major crops: corn and beef (Monterroso-Rivas et al 2011b); (Buechler, 2009). Water deficits for Northwestern Mexico, the primary region of irrigated grain farming, may be substantial due to projected larger temperature increases and reductions in precipitation up to 30% greater than the rest of the country by 2050 (mean of ensemble of 18 models, A2 and A1B)(Magana *et al*., 2012). Irrigation, an important source of mitigation during water deficits, is limited in Mexico (Skoufias *et al*., 2011).

Although projected increases in precipitation may contribute to an overall increase in the productivity of rangeland in some regions (Monterroso Rivas *et al*., 2011b)2011a, the direct effects of temperature on livestock stress is expected to reach the dangerous zone by 2020 and continue to rise in Veracruz (A2 and B2, three GCMs) (Hernandez *et al*., 2011). Reduced frost threat in some regions would enhance corn yields (Conde *et al*., 2006). However, decreases from 6.2% currently to between 3% and 4.3% are projected in the land classified as "suitable" for rain-fed corn production (UKHadley B2) (ECHAM5/MPI A2) by 2050 (Monterroso-Rivas et al 2011b). The distribution of most races of corn is expected to be reduced and some eliminated by 2030 (A2, three climate models) (Ureta et al 2012). Coffee, an economically important crop supporting 500,000 primarily indigenous households (Gonzalez Martinez 2006), is projected to decline 34% by 2020 in Veracruz (Gay *et al*., 2006) and from 265400 ha today to 6000 ha by 2050 in Chiapas (A2a, mean of 15 models) (Schroth *et al*., 2009).

26.5.3. Adaptation

Adaptation can off-set projected declines in yields and capitalize on emerging opportunities. Importantly, adaptation imposes both costs and risks onto producers (Wolfe *et al*., 2008), and in some cases will be insufficient (Boyd and Ibarraran, 2009; Prato *et al*., 2010). Technological improvements can increase yield under normal conditions but do not protect harvests from extreme events (USGCRP, 2009; Wittrock *et al*., 2011). Some adaptation strategies may be economically precluded for low-value crops, or maladaptive for other sectors (depletion of groundwater supplies and increased energy consumption). Strong promotion of capital-intensive adaptation strategies may be beyond the means of smallholders (Mercer et al 2012).

26.5.3.1. Adaptation Options

Coping mechanisms, such as insurance, the purchase of livestock feed during droughts, or increased application of herbicides (Craine *et al*., 2010), may be necessary but insufficient, and certainly not optimal. Consideration of the potential for broad application, co-benefits, and unintended consequences of adaptation options will enhance adaptation planning (Belliveau *et al*., 2006). Planting varieties better suited to future climate conditions has high potential (Bootsma *et al*., 2005; Eakin and Appendini, 2008; Coles and Scott, 2009; Paudel and Hatch, 2012), and has been in use by farmers in the past (Conde *et al*., 2006; Nadler and Bullock, 2011).

Other options have multiple co-benefits. Low- and no-till practices that significantly reduce soil erosion and runoff also protect crops from extreme precipitation (Zhang and Nearing, 2005), retain soil moisture, and reduce greenhouse gas emissions (Suddick *et al*., 2010). Strategies to maintain productivity of grazing lands, such as planting legumes and weed management, enhance soil carbon sequestration (Follett and Reed, 2010). Shade-producing perennials greatly enhances soil moisture retention (Lin, 2010), and contributes to local cooling (Georgescu *et al*., 2011). Increasing crop diversity, an historic risk management strategy that mediates the impacts of climate and market shocks (Eakin and Appendini, 2008), enhances management flexibility (Chhetri *et al*., 2010), and is more conducive to organic practices, which produce lower greenhouse gas emissions (Jackson and Wheeler 2010).

26.5.3.2. Criteria for Adaptation Observed in Existing Practices

High prices may motivate investments in adaptation(Li *et al*., 2011). However, market forces and technical feasibility alone are unlikely to lead to sectoral-level adaptation (Kulshreshtha, 2011), thus institutional support is key, found to be inadequate in many contexts (Klerkx and Leeuwis, 2009; Jacques *et al*., 2010; Tarnoczi and Berkes, 2010; Brooks and Loevinsohn, 2011; Alam *et al*., 2012; Anderson and McLachlan, 2012)(Bryant *et al*. 2008). Small Mexican farmers face limited access to credit and insurance (Eakin, 2006; Wehbe *et al*., 2008; Saldaña-Zorilla and Sandberg, 2009; Walthall *et al*., 2012). In some sectors we are seeing investments in adaptation. International coffee retailers and non-governmental organizations are engaged in enhancing coffee farmers' adaptive capacity (Schroth *et al*., 2009; Soto-Pinto and Anzueto, 2010).

Other key criteria are access to and quality of information (Tarnoczi and Berkes, 2010; Tarnoczi, 2011; Baumgart-Getz *et al*., 2012; Tambo and Abdoulaye, 2012) and the social networks needed to exchange that information and offer mutual support, particularly stronger ties among producers (Chiffoleau, 2009; Wittrock *et al*., 2011; Baumgart-Getz *et al*., 2012). Social networks may be especially important to the level of awareness and concern farmers hold about climate change, which in turn has motivated adaptation (Sánchez-Cortéz and Chavero 2011)(Eakin *et* al., forthcoming)(Frank *et al*., 2010).

26.6. Human Health

North America has been an important source of research on climate-related health impacts and vulnerability. Large national assessments of climate and health have been carried out in both the US and Canada (see reference to them in section 26.1). These have highlighted the potential for changes in impacts of extreme storm and heat events, air pollution, pollen, and infectious diseases, drawing from a growing NA research base analyzing observed and projected relationships among weather variables, vulnerability factors and health outcomes. The causal pathways leading from climate to health are complex, and can be modified by intervening factors including economic status, pre-existing illness, age, other health risk factors, access to health care, built and natural environments, adaptation actions and others. Human health is an important dimension of adaptation planning at the local level, much of which has so-far focused on warning and response systems to extreme heat events (New York State CAC, 2012).

26.6.1. Observed Impacts

26.6.1.1. Storm-Related Impacts

The magnitude of health impacts of extreme storms depends on the interaction between hazard exposure and characteristics of the affected communities (Keim, 2008). Coastal and other low-lying infrastructure and populations can be vulnerable due to flood-related interruptions in communications, healthcare access, and mobility. Health impacts include direct effects on traumatic death and injury (e.g., drowning; impacts of blowing and falling objects; contact with power wires) as well as indirect, longer-term effects related to contamination of water and soil, vector-borne diseases, respiratory diseases and mental health (Gamble *et al*., 2008). Infectious disease impacts from flooding include creation of breeding sites for vectors (Ivers and Ryan, 2006) and bacterial transmission through contaminated water and food sources causing gastrointestinal disease. Chemical toxins can be mobilized from industrial or contaminated sites (Euripidou and Murray, 2004) . Elevated indoor mold levels associated with flooding of buildings and standing water are identified as risk factors for cough, wheeze and childhood asthma

(Bornehag *et al*., 2001; Jaakkola *et al*., 2005). Mental health impacts of extreme storms have received relatively little study to date (Berry *et al*., 2010). Stress of evacuation, property damage, economic loss, and household disruption are some of the mental health triggers (Weisler *et al*., 2006; Gamble *et al*., 2008). In the period of recent warming, i.e., 1970 to 2010, there has been no clear trend in US hurricane deaths, once the singular Katrina event is set aside (National Hurricane Center).

26.6.1.2. Extremes of Temperature

A large body of literature in North America has associated high temperatures with increased mortality and morbidity (e.g., Medina-Ramon and Schwartz, 2007; Anderson and Bell, 2009; Deschenes *et al*., 2009; Knowlton *et al*., 2009; O'Neill and Ebi, 2009; Cueva-Luna *et al*., 2011; Hurtado-Díaz *et al*., 2011; Romero-Lankao *et al*., 2012). Extremely cold temperatures have also been associated with increased mortality (Medina-Ramon and Schwartz, 2007) , an effect separate from the seasonal phenomenon of excess winter mortality, which does not appear to be directly related to cold temperatures (Kinney, 2012). Most available NA evidence derives from the US and Canada, though one recent study reported significant heat- and cold-related mortality impacts in Mexico City (McMichael *et al*., 2008).

26.6.1.3. Air Quality

Ozone and particulate matter (e.g., PM2.5 and PM10) have been associated with adverse health effects in many locations in North America (Romero-Lankao *et al*., 2013). Weather and climate affect concentrations of air pollution over multiple scales in time and space. 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). However, long-term trends in anthropogenic air pollution in NA are more influenced by trends in emission from sources than by climate, and to-date, there has been no discernible climate-induced trend in outdoor air quality in NA. Forest fires are an important source of particle emissions in NA, and can lead to increased cardiac and respiratory diseases incidence, as well as direct mortality (Rittmaster *et al*., 2006; Ebi *et al*., 2008). The indoor environment also can affect health in many ways, e.g., via penetration of outdoor pollution, emissions or pollutants indoors, moisture-related problems, and transmission of respiratory infections. Indoor moisture leads to mold growth, a problem that is exacerbated in colder regions such as northern NA in the winter. Climate variability and change is *likely* to affect indoor air quality, but with direction and magnitude that remains largely unknown (IOM, 2011).

26.6.1.4. Pollen

Exposure to pollen has been associated with a range of allergic outcomes, including exacerbations of allergic rhinitis (Cakmak *et al*., 2002; Villeneuve *et al*., 2006) and asthma (Delfino, 2002). Temperature and precipitation in the months prior to the pollen season affects production of many types of tree and grass pollen (Reiss and Kostic, 1976; Minero *et al*., 1998; Lo and Levetin, 2007; U.S. EPA, 2008). Ragweed pollen production is responsive to temperatures and concentrations of atmospheric carbon dioxide (Ziska and Caulfield, 2000; Wayne *et al*., 2002; Ziska *et al*., 2003; Singer *et al*., 2005). Because pollen production and release can be affected by temperature, precipitation, and CO_2 concentrations, it is possible that pollen exposure and allergic disease morbidity could change in response to climate change. However, to date, the only evidence for observed climate-related impacts are for the timing of the pollen season. Many studies have indicated that pollen seasons are beginning earlier (Emberlin *et al*., 2002; Rasmussen, 2002; Clot, 2003; Teranishi *et al*., 2006; Frei and Gassner, 2008; Levetin and Van, 2008; Ariano *et al*., 2010). Evidence of an earlier start to the pollen season has recently been reported in the United States; some pollen types, such as ragweed, also have shown an increase in season length (Ariano *et al*., 2010; Ziska *et al*., 2011). Research on trends in NA has been hampered by the lack of long-term, consistently collected pollen records (U.S. EPA, 2008).

26.6.1.5. Waterborne Diseases

Waterborne infections are an important source of morbidity and mortality in North America. Commonly reported infectious agents in recent US and Canadian outbreaks include legionella bacterium, the cryptosporidium parasite, campylobacter, and giardia (CDC, 2011), (Séguin 2008). Cholera remains an important agent in Mexico (Greer *et al*., 2008). Risk of waterborne illness is greater among the poor, infants, elderly, pregnant women, and immunocompromised individuals (Rose *et al*., 2001; Gamble *et al*., 2008) . In Mexico City, declining water quality has led to ineffective disinfection of drinking water supplies (Mazari-Hiriart *et al*., 2005; Sosa-Rodriguez, 2010).

Changes in the temperature and the hydrological cycle can influence the risk of waterborne diseases (Curriero *et al*., 2001; Greer *et al*., 2008; Harper *et al*., 2011). Floods enhance the potential for runoff to carry sediment and pollutants to water supplies (Karl *et al*., 2009). Disparities in access to treated water were identified as a key determinant of under age-5 morbidity due to water borne illnesses in the central State of Mexico (Jimenez-Moleon and Gomez-Albores, 2011).

26.6.1.6. Vectorborne Diseases

The extent to which climate change has altered, and will alter, the geographic distribution of vectors of infectious disease remains uncertain because of the inherent complexity of the ecological system. Spatial and temporal distribution of disease vectors depend not only on climate factors, but also on land use/change, socio-economic and socio-cultural factors, prioritization of vector control, access to health care and human behavioral responses to perception of disease risk, among other factors (Lafferty, 2009; Wilson, 2009). Although temperature drives important biological processes in these organisms, variability in climate on a daily, seasonal or interannual scale may result in organism adaptation and a shift in geographic range, not necessarily an expansion in range (Lafferty, 2009; Tabachnick, 2010; McGregor, 2011). This shift may alter the incidence of disease depending on host receptiveness and immunity, as well as the ability of the pathogen to evolve so that strains are more effectively and efficiently acquired (Reiter, 2008; Beebe *et al*., 2009; Rosenthal, 2009; Russell, 2009; Epstein, 2010).

North Americans are currently at risk from a number of vector-borne diseases, including Lyme disease (Ogden *et al*., 2008; Diuk-Wasser *et al*., 2010), dengue fever (Jury, 2008; Ramos *et al*., 2008; Johansson *et al*., 2009; Degallier *et al*., 2010; Kolivras, 2010; Lambrechts *et al*., 2011; Riojas-Rodriguez *et al*., 2011; Lozano-Fuentes *et al*., 2012), West Nile virus (Morin and Comrie, 2010; Gong *et al*., 2011) and Rocky Mountain spotted fever, to name a few. There is increasing risk from invasive vector-borne pathogens, such as chikungunya (Ruiz-Moreno *et al*., 2012) and Rift Valley fever viruses 8(Greer *et al*., 2008).

26.6.2. Projected Impacts

Projecting future public health consequences of gradual climate warming is challenging, due in large 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 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. However, climate warming will lead to continuing health stresses related to extreme high temperatures, particularly for the northern parts of North America. The health implications of warming winters remain uncertain (Kinney, 2012).

There is a large literature examining future climate influences on outdoor air quality in North America, particularly for ozone (Kunkel *et al*., 2007; Tao *et al*., 2007; Holloway *et al*., 2008; Lin *et al*., 2008; Nolte *et al*., 2008; Wu *et al*., 2008; Avise *et al*., 2009; Chen *et al*., 2009; Liao *et al*., 2009; Racherla and Adams, 2009; Lin *et al*., 2010; Tai *et al*., 2010). This work suggests with *medium confidence* that ozone concentrations could increase under future climate change scenarios if emissions of precursors were held constant (Jacob and Winner, 2009a). The literature for PM2.5 is more limited than that for ozone (Liao *et al*., 2007; Tagaris *et al*., 2008; Avise *et al*., 2009; Pye *et al*., 2009;

Mahmud *et al*., 2010). Several recent studies have projected future health impacts due to air pollution in a changing climate (Bell *et al*., 2007; Tagaris *et al*., 2009; Chang *et al*., 2010; Tagaris *et al*., 2010). Using a range of climate/air quality models and scenarios as well as a range of health and demographic projections, Post and colleagues (2012) found that future mortality effects of ozone tended to increase in a changing climate. Similar findings were previously reported for the eastern and northeastern US (Knowlton *et al*., 2004; Bell *et al*., 2007). Future changes in seasonal timing of pollen release are *likely*. Another driver of future pollen might be changing patterns of vegetation, which are projected to change in the future.

Regarding clean water supplies, extreme precipitation can overwhelm combined sewer systems and lead to overflow events that can threaten human health (Patz *et al*., 2008). Conditional on a future increase in such events, we can anticipate increasing risks related to water-borne diseases.

Whether future warmer winters in the United States and Canada will promote transmission of diseases like dengue and malaria is uncertain, in part, because of access to amenities such as screening and air-conditioning that provide barriers to human-vector contact. Socio-economic factors also play important roles in determining risks. Better longitudinal datasets and empirical models are needed to address knowledge gaps in research on climate-sensitive infectious diseases, as well as to provide a better mechanism for weighting the roles of external drivers such as climate change on a macro/micro scale, human-environmental changes on a regional to local scale and extrinsic factors in the transmission of vector-borne infectious diseases (Wilson, 2009; McGregor, 2011).

26.6.3. Adaptation Responses

Early warning and response systems can be developed to build resilience to severe climate-relate events (Ebi, 2011) and protect susceptible populations, which include infants, children, the elderly, individuals with pre-existing diseases, and those living in socially and/or economically disadvantaged conditions (Pinkerton *et al*., 2012). At the urban and regional level, adaptation planning to build resilience for health systems in the face of changing climate is a growing priority (Kinney *et al*., 2011).

Adaptation to heat events can occur via physiologic mechanisms, indoor climate control, urban-scale cooling initiatives, and as a result of warning and response systems. Additional research is needed on the extent to which warning systems prevent deaths (Harlan and Ruddell, 2011). Efforts to reduce GHG emissions could provide health co-benefits, including reductions in heat-related and respiratory illnesses (Health Chapter, US National Climate Assessment). Tree planting initiatives in cities are often motivated by climate adaptation goals. Health benefits related to pollen can be promoted by careful species selection.

26.7. Infrastructures and Other Economic Sectors

This section covers the following economic sectors not addressed elsewhere in the chapter: manufacturing, mining, energy, and services and infrastructures (insurance, construction, housing, and transportation). Available research typically focuses on the direct impact of climate on economic activity, although recent studies have begun to assess the indirect impacts resulting from, for example, scarce supplies during droughts or disruption of transportation and other infrastructure services from storms or floods.

There is mounting evidence that many sectors across North America are adapting to the risk of loss and damage from weather perils. The limited literature available largely reports a range of adaptive practices and adaptation responses to experience with extreme events, and only an emerging consideration of proactive adaptation in anticipation of future global warming.

26.7.1. Manufacturing

26.7.1.1. Observed Impacts

There is little literature focused on climate change and manufacturing, although one study suggested that manufacturing is among the most sensitive sectors to weather in the United States (Lazo *et al*., 2011). Weather affects, for example, the supply of raw material (e.g. agricultural inputs for food manufacturing), the production process (e.g. water availability and energy demands for cooling/heating), the transportation of goods (e.g. storm delays can close roads and affect travel time), and the demand for certain products. In 2011, automobile manufacturers in North America experienced production losses associated with shortages of components due to flooding in Thailand (Newswire, 2011). In 2013, reduced cattle-supply and higher feed prices associated with several years of drought in Texas led to a decision to close a beef processing plant (Beef Today Editors, 2013). Other major storms, like Hurricanes Sandy, Katrina and Andrew, significantly disrupted manufacturing activity across North America This included delays in production when plants were forced to shutdown due to direct damages and/or loss of electricity and supply disruptions due to unavailability of parts, as well as difficulties delivering products associated with compromised transportation networks. (Baade *et al*., 2007; Dolfman *et al*., 2007).

26.7.1.2. Projected Impacts

The drier conditions projected for many regions of North America (Sun *et al*., 2008; Seager and Vecchi, 2010a; Wehner *et al*., 2011) would present challenges, especially for manufacturers located in regions already experiencing water stress. This could lead to increased conflicts over water between sectors and regions, and affect the ability of regions to attract new facilities or retain existing manufacturing operations. A modeling study which considered the impact of projected changes in precipitation on 70 industries in the United States between 2010 and 2050 suggested the potential for losses in production and employment due to declines in water availability and the interconnected nature of different industries (Backus *et al*., 2013). For instance, costs incurred by chemical companies responding to water deficits could translate to reduced supply or higher costs of chemical products needed by other industries, such as construction, textiles and agriculture (Backus *et al*., 2013). Declining water levels in the Great Lakes would increase shipping costs by restricting vessel drafts and reducing vessel cargo volume (Millerd, 2011).

For manufacturers dependent on raw materials from mining, the impacts on transportation (*see* section 26.7.5.2) could be high. Another potential concern for manufacturing relates to impacts of heat on worker safety and productivity. Several studies suggest that higher temperatures and humidity would lead to decreased productivity and increased health risks (e.g., Kjellstrom *et al*., 2009; Hanna *et al*., 2011; Kjellstrom and Crowe, 2011).

26.7.1.3. Adaptation

There is evidence that some companies are beginning to recognize the risks climate change presents to their manufacturing operations, and consider strategies to build resilience to these risks (National Round Table on the Environment and the Economy, 2012). Air conditioning is a viable and effective adaptation option to address some of the impacts of warming across much of North America, though it does incur additional costs (Scott *et al*., 2008a). Coca Cola has a water stewardship strategy focusing, among other things, on improving water use efficiency at its manufacturing plants, while Rio Tinto Alcan is assessing climate change risks for their operations and infrastructure, which include vulnerability of transport systems, increased maintenance costs, and disruptions due to extreme events (National Round Table on the Environment and the Economy, 2012 (National Round Table on the Environment and the Economy, 2012).

26.7.2. Mining

26.7.2.1. Observed Impacts

Climatic sensitivities of mining activities (including exploration, extraction, processing, operations, transportation and site remediation) have been noted in the limited literature (Chiotti and Lavender, 2008; Furgal and Prowse, 2008; Meza-Figueroa *et al*., 2009; Ford *et al*., 2010; Gómez-álvarez *et al*., 2011; Kirchner *et al*., 2011; Locke *et al*., 2011; Pearce *et al*., 2011; Stratos Inc, 2011). Drought-like conditions have affected the mining sector by limiting water supply for operations (Pearce *et al*., 2011), enhancing dust emissions from quarries (Pearce *et al*., 2011) and increasing concentrations of heavy metals in sediments (Gómez-álvarez *et al*., 2011). Heavy precipitation events have caused untreated mining wastewater to be flushed into river systems (Pearce *et al*., 2011). High loads of contamination (metals, sulfate and acid) at three mine sites in the United States were measured during rainstorm events following dry periods (Nordstrom, 2009).

26.7.2.2. Projected Impacts

An increase in heavy precipitation events and more intense and/or frequent droughts projected for much of North America is likely to affect mining (Warren and Egginton, 2008; Nordstrom, 2009; Gutzler and Robbins, 2011). Although climate change is perceived as an emerging risk, and in some cases, a potential opportunity by Canadian mine practitioners (Ford *et al*., 2010; Ford *et al*., 2011; Pearce *et al*., 2011; National Round Table on the Environment and the Economy, 2012), potential impacts on transportation are perceived as a key issue for Canadian mines (Ford *et al*., 2011), as is limited water availability (Acclimatise, 2009) from projected drier conditions (Sun *et al*., 2008; Seager and Vecchi, 2010a).

A study on acid rock damage drainage in Canada concluded that while the mining sector could minimize the impacts of incremental change to 2050, an increase in heavy precipitation events presented a greater risk of both environmental impacts and economic costs (Stratos Inc, 2011) Climate change impacts that affect the bottom-line of mining companies (through direct impacts or associated costs of adaptation), would have consequences for employment, for both the mining sectors and local support industries (Backus *et al*., 2013).

26.7.2.3. Adaptation

Despite awareness of the potential role of adaptation within the mining industry, there is presently little evidence of proactive adaptation planning within the mining sector (Acclimatise, 2009; Ford *et al*., 2010; Ford *et al*., 2011). However, adjustments to management practices to deal with short-term water shortages, including reducing water intake, increasing water recycling and establishing infrastructure to move water from tailing ponds, pits and quarries, have worked successfully in the past (Chiotti and Lavender, 2008). Climate change is now considered in the design phase of mines in Canada, as a requirement of the Canadian environmental assessment process (Prowse *et al*., 2009). Integrating climate change considerations at the mine planning and design phase increases the opportunity for effective and cost-efficient adaptation (Stratos Inc, 2011).

26.7.3. Energy

26.7.3.1. Observed Impacts

The energy is particularly sensitive to climate change though literature is unequally distributed among countries. Across the United States, energy demand for cooling has increased over the last 40 years, while demand for heating has decreased.(Dell et al.) (2013), note that recent extreme weather events such as hurricanes have disrupted energy production and distribution.

26.7.3.2. Projected Impacts

In Canada, a net decrease in annual energy demand is projected by 2050 and by 2100 (Isaac and Van Vuuren, 2009). The net change in United States energy demand by 2080 is estimated to range from -15 to +4% (Wilbanks *et al.*, 2008), , with peak demand for electricity increasing more than the average demand for electricity, and capacity expansion required in many areas.

Rising temperatures (which reduce thermal power plant efficiencies) and limited water supplies (which affect power plant cooling) are projected to affect both energy production and hydropower and renewable energy sources. 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) (Wilbanks *et al.*, 2008).

The magnitude of projected impacts on hydropower potential will vary significantly between regions and within drainage basins, as flow regimes shift in response to changing climate (Desrochers *et al.*, 2009; Kienzle *et al.*, 2012; Shrestha *et al.*, 2012). Annual mean hydropower production in the St. Lawrence and Great Lakes region of Canada is estimated to decrease by 1.8% in the period 2010–2039 and then increase by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively (Minville *et al.*, 2009). Regionally in the United States, 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 (Wilbanks *et al.*, 2008).

26.7.4. Insurance

26.7.4.1. Observed Impacts

Property insurance and reinsurance companies across North America experienced a significant increase in severe weather damage claims paid over the past three or four decades(Cutter and Emrich, 2005; Bresch and Spiegel, 2011; Munich Re, 2011). Most of the increase in insurance costs has been attributed to increasing exposure of people and assets in areas of risk (Pielke Jr *et al.*, 2008; Barthel and Neumayer, 2012). A role for climate change has not been excluded, but the increase to date in damage claims is largely due to growth in wealth and population(Field *et al.*, 2012).

Severe weather and climate risks have emerged over the past decade as the leading cost for property insurers across North America, resulting in significant change in industry practices. The price of insurance increased in regions where the risk of loss and damage has increased, and discounts were introduced where risks have been reduced.

26.7.4.2. Projected Impacts

Without adaptation, there is an expectation that severe weather insurance damage claims will increase significantly over the next several decades across North America (World Bank, 2010). The risk of damage is expected to rise due to continuing growth in wealth, the population living at risk, and climate change. There is also an expectation that some weather perils in North America will increase in severity, including Atlantic hurricanes and the area burned by wildfire (Karl *et al.*, 2008), and frequency, including intense rainfall events (Field *et al.*, 2012).

26.7.4.3. Adaptation

Most adaptation in the insurance industry, one of the most studied sectors with respect to adaptation to present and future weather and climate impacts (Mills and Lecomte, 2006; Mills, 2007; Mills, 2009; Autorite des Marches

Financiers, 2011; Leurig, 2011), has been in response to an increase in severe weather damage, with little evidence of proactive adaptation in anticipation of future climate change.

Catastrophe models were developed to help insurers manage the risk of insolvency, their capital needs and the appropriate use of reinsurance. In addition to pricing decisions based on an actuarial analysis of historic loss experience, many insurance companies now use model information to help determine the prices they charge and discounts they offer. Most insurance companies have established specialized claims handling procedures for responding to catastrophic events (Kovacs, 2005; Mills, 2009).

A recent Bank of International Settlements study of more than 2,000 major catastrophes since 1960 found that insurance is a critical adaptive tool available to help society minimize the adverse economic consequences of natural disasters. In the United States and Canada homeowners make extensive use of insurance to manage a broad range of risks, and those with insurance recover quickly following most extreme weather events. However the majority of public infrastructure is not insured and it frequently takes more than a decade before government services fully recover. In contrast Mexico has a well-developed program for financing the rebuilding of public infrastructure following a disaster (FONDEN) but insurance markets are only beginning to emerge for homeowners and businesses. (In 2010, per capita spending on property and casualty insurance was US$2,112.80 in the United States, US$1,870.60 in Canada and US$92.90 in Mexico (Bevere *et al*., 2012).)
Insurance companies are also working to influence the behavior of their policyholders to reduce the risk of damage from climate extremes (Kovacs, 2005; Anderson *et al*., 2006; Mills, 2009). For example, the industry supports the work of the Insurance Institute for Business and Home Safety in the United States, and the Institute for Catastrophic Loss Reduction in Canada working to champion change in the building code and communicate to property owners, governments and other stakeholders best practices for reducing the risk of damage from hurricanes, tornadoes, winter storms, wildfire, flood and other extremes.

26.7.5. Other Service Industries

Most service industries are less climate-sensitive than goods-producing industries, except insurance and tourism (Ford *et al*., 2010; Ford *et al*., 2011). Three broad categories of impacts of climate extremes can affect tourism destinations, competitiveness, and sustainability. The first relates to direct impacts on hotels, access roads and other tourist infrastructures; on such operating costs as heating/cooling, snowmaking, irrigation, food and water supply, evacuation, and insurance; on emergency preparedness requirements; and on business disruption (e.g., sun-and-sea or winter sports holidays). The second category refers to indirect environmental change impacts of extreme events on biodiversity and landscape change (e.g., coastal erosion), which may negatively affect the quality and attractiveness of tourism destinations. Particular tourist regions can suffer as a result of tourism-adverse perception after occurrence of the extreme event itself (Scott *et al*., 2008a).

26.7.5.1. Construction and Housing

26.7.5.1.1. Observed impacts

The risk of damage from climate perils is a significant issue for the housing and construction industries, though little research has systematically explored the topic (Morton *et al*., 2011).
There are no public sources of data that track damage to the built environment from weather events in North America. Private data from insurance companies report a significant increase in severe weather damage to buildings and other insured infrastructure over several decades. Studies indicate that the increase in reported damage is largely due to rising wealth and populations living at risk.

26.7.5.1.2. Projected impacts

Most studies project a significant further increase in damage to homes, buildings and infrastructure. Affordable adaptation in design and construction practices could reduce much of the risk of climate damage for new buildings and infrastructure, likely involving reform in Building Codes and other standards. However, adaptation best practices in design and construction are often prohibitively expensive to apply to existing buildings and infrastructure, so much of the projected increase in climate damage risk involves existing buildings and infrastructure.

26.7.5.1.3. Adaptation

Engineering and construction knowledge exists to design and construct new buildings to accommodate the risk of damage from historic extremes and anticipated changes in severe weather (Kelly, 2010; Ministry of Municipal Affairs and Housing, 2011; Institute for Business and Home Safety, 2012). Older buildings may be retrofit to increase resilience, but these changes are often more expensive to introduce into an existing structure than if they were included during initial construction.

The housing and construction industries have made advances toward climate change mitigation by incorporating energy efficiency in building design (Heap, 2007). Less progress has been made in addressing the risk of damage from extreme weather events (Kenter, 2010). In some markets, like the Gulf Coast of the United States, change is under way in the design and construction of new homes in reaction to recent hurricanes, but in most markets across North America there has been little change in building practices. The cost of adaptation measures combined with limited long-term liability for future buildings influenced some builders to take a wait-and-see attitude (Morton *et al.*, 2011). Exploratory work is under way to consider implementation of building codes that would focus on historic weather experience and also introduce expected future weather risks (Auld *et al.*, 2010; Ontario Ministry of Environment, 2011).

26.7.5.2. Transportation

26.7.5.2.1. Observed impacts

Transportation infrastructure across North America is aging, or inadequate (Mexico) which may make it more vulnerable to damage from extreme events, like intense rainfall washing away roads or rails, and slow onset perils like sea level rise and melting permafrost. The American Society for Civil Engineers estimates that more than US$2 trillion is needed to bring infrastructure in the United States up to “good condition” (ASCE, 2009, p.6). The U.S. Department of Transportation estimated that between US$100 and US$175 billion would be needed in the next 20 years to upgrade U.S. highways (Federal Transit Administration, 2008). Canadian infrastructure had an investment deficit of C$125 billion in the 1980s and 1990s (Mirza and Haider, 2003).

26.7.5.2.2. Projected impacts

Scholarship on projected climate impacts on transportation infrastructure focuses mostly on US and Canada. The Transportation Research Board found that increases in high temperature events, intense precipitation, drought, sea level, and storm surge could affect transportation across the United States. The greatest risks would be to coastal transportation infrastructure, but there could be benefits to marine and lake transportation in high latitudes from shorter period with ice cover (Transportation Research Board, 2008). A one meter sea level rise combined with a 7 meter storm surge could inundate over half of the highways, arterials, and rail lines in the United States Gulf coast (Savonis *et al.*, 2008). While in southern Canada by the 2050s, low temperature cracking from either the B2 or A2 scenarios would decrease, structures would freeze later and thaw earlier, and higher extreme temperatures would increase the potential for rutting (Mills *et al.*, 2009) and related maintenance and rehabilitation costs (Canadian Council of Professional Engineers, 2008).

A 1 to 1.5°C increase in global mean temperature would increase the costs of keeping paved and unpaved roads in the United States in service by, respectively, US$1.9 to US$2.8 billion per year by 2050 (Chinowsky *et al*., Submitted). Up to 100,000 bridges in the United States crossing rivers and streams could be made vulnerable by increasing peak flows in the mid- and late-21st Century under the A1B and A2 scenarios. Currently deficient bridges, about one-fourth of the current bridges, would be most vulnerable. Strengthening the vulnerable bridges to be more resilient to climate change is estimated to cost US$138 to US$247 billion, but the costs could be reduced by 27 to 28% if currently deficient bridges are strengthened (Wright *et al*., 2012).

26.8. Urban and Rural Settlements

26.8.1. Weather and Climate Impacts

Observed impacts in North American settlements such as livelihood stresses and changes in access to essential services have been attributed*, with different degrees of certainty,* to climate variability and change including but not limited to: changes in mean climate conditions (SLR, temperature and precipitation) and in extreme events.

26.8.1.1. Changes in Mean Conditions

In coastal zones, SLR and storm surges have reduced development options and increased hazard risk. This process was observed dramatically in New York in 2012, but it is also affecting other settlements along the mid-Atlantic, the Gulf of Mexico, and the St. Lawrence (Kirshen *et al*., 2008; Friesinger and Bernatchez, 2010; Zavala-Hidalgo *et al*., 2010; Rosenzweig *et al*., 2011; Tebaldi *et al*., 2012).

During the 20th century temperatures increased faster in cities compared to rural areas, due mainly to the urban heat island (UHI) (Harlan and Ruddell, 2011) resulting from land and energy use patterns.

26.8.1.2. Extreme Events

Droughts are among the more notable extreme events affecting North American settlements recently, with severe occurrences in the Canadian Prairies (2001-2) (Wheaton *et al*., 2007) and Southwestern US - Northern Mexico (2010-2012)—argued to be the most severe in a century (MacDonald, 2010a). The 2012 drought affected 80% of agricultural land in the U.S., with 2,000 counties designated disaster zones by September (USDA Economic Research Service, 2012), http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx, accessed November 25, 2012). Road pavement in Chicago buckled under temperatures over 100oF (CBS Chicago, 2012). In Colorado two wildfires burned over 600 homes (NCDC (National Climate Data Center), 2013). Among the most severely affected were indigenous peoples, such as the Rarámuri of Chihuahua (Imison, 2012)

Pest outbreaks such as the Mountain Pine Beetle infestation that emerged across western North America early in the 21st Century, describe another significant recent event attributed to climate change, affecting rural and peri-urban settlements (Kurz *et al*., 2008a). *Wildfires* have also had notable effects (Box 26-2).

Extreme storms have also had their effect, although changes in their frequency are difficult to attribute to anthropogenic climate change. While immediate health and safety threats associated with such events have been minimized in most cases, impacts on the built environment have been costly. Heavy precipitation, storm surges, flash-floods and wind have compromised homes and business (Comfort, 2006; Kirshen *et al*., 2008; Jonkman *et al*., 2009; Romero-Lankao, 2010), including flooding in the U.S. Midwest (2011), and hurricanes in southern Mexico (2004-5). Hurricane Wilma alone caused $1.8 billion in damage, among the biggest insurance losses in Latin American history (Galindo *et al*., 2009).

Lives and livelihoods have been affected by extreme events. Examples include:

- A relationship between heat and excess mortality in cities, with city-specific thresholds varying with latitude and hazard magnitude (O'Neill and Ebi, 2009; Romero-Lankao *et al.*, 2012).
- The Canadian forest sector has shed 100,000 jobs since 2005, attributed in part to the mountain pine beetle (Parkins and MacKendrick, 2007; Parkins, 2008; Holmes, 2010; MacKendrick and Parkins) identified 30 communities and 25,000 families in British Columbia directly affected.
- Observed shifts in Pacific Northwest marine ecosystems attributed to climate change have restricted fisheries; northeast fisheries are projected to follow suit (USGCRP, 2009).
- Loss of 3.2 million tons of maize placing 2.5 million Mexicans at risk of food insecurity (DGCS, 2012), http://www.dgcs.unam.mx/boletin/bdboletin/2012_053.html, accessed November 25, 2012).
- Drought-related economic and employment losses in the Canadian Prairies (Wheaton *et al.*, 2007; Kulshreshtha, 2011).
- Intensified inequalities in vulnerability to wildfire between amenity migrants and low-income residents in peri-urban areas (Collins and Bolin, 2009).

Human settlements are differentially affected by impacts to ecological services. Among the most essential human services, changes in water supplies have immediate implications for economies and health (section 26.3).

26.8.2. Observed Factors and Processes Associated with Vulnerability

Differences in severity of climate impacts are strongly influenced by context-specific factors and processes exacerbating or ameliorating vulnerability (Table 26-1; Cutter *et al.*, 2013), each of which is more pertinent to some types of settlements than others. Human settlements simultaneously face a multilevel array of non-climate-related risks (e.g., economic, industrial, technological) that contribute to climate change vulnerability (McGranahan *et al.*, 2007; Satterthwaite *et al.*, 2007; Romero-Lankao and Dodman, 2011). In the following we highlight key sources of vulnerability for urban and rural systems.

[INSERT TABLE 26-1 HERE
Table 26-1: Dimensions of vulnerability. Source: Romero-Lanka, 2012.]

26.8.2.1. Urban Settlements

Geography: The concentration of populations, economic activities, cultural amenities and built environments characteristic of urban areas in highly-exposed locations such as coastal and arid areas creates hazard risks. Of particular concern are Canadian prairie cities; US-Mexico border cities; major U.S. urban areas including Boston, New York, Chicago, Washington, DC, Los Angeles, and Mexico City (Bin *et al.*, 2007; Collins, 2008; Kirshen *et al.*, 2008; Collins and Bolin, 2009; Gallivan *et al.*, 2009; Hayhoe *et al.*, 2010; Romero-Lankao, 2010; Rosenzweig *et al.*, 2010; Wittrock *et al.*, 2011). Without effective policies, environmental impacts such as poor urban air quality can exacerbate climate impacts (Romero-Lankao *et al.*, 2013).

Interactive causes and effects: As with all complex systems, the interaction of multiple processes (e.g., disaster management, economic stratification, high-magnitude hazards) can contribute to urban vulnerability. Research increasingly emphasizes the interrelated nature of economic, social and ecological impacts (Gasper *et al.*, 2011). For instance, under current local financial constraints, climate-related economic losses can reduce resources available to address social issues, thus threatening institutional capacity and urban livelihoods (Kundzewicz *et al.*, 2008).

Urbanization changes land-use and land-surface physical characteristics (e.g., surface albedo, Chen *et al.*, 2011). A 34% increase in U.S. urban land development (Alig *et al.*, 2004) between 1982 and 1997 had implications for water supplies and extreme event impacts. Effects on water are of special concern, as urbanization can enhance or reduce precipitation, depending on climate regime, geographical location and regional patterns of land, energy and water use (Cuo *et al.*, 2009). Urbanization also has significant impacts on flood climatology through atmospheric processes tied to the Urban Heat Island (UHI), the Urban Canopy Layer (UCL), and aerosol composition of airsheds

(Ntelekos *et al*., 2010) . The UHI, which varies across and within cities (Harlan *et al*., 2008; Miao *et al*., 2011), can increase health risks (health section).

Urbanization imposes path dependencies that can amplify or attenuate vulnerability (Romero Lankao and Qin, 2011). For example, the overexploitation of Mexico City's aquifer by 19.1 - 22.2 m^3/s has reduced groundwater levels and caused subsidence, undermining building foundations and infrastructure and increasing residents' vulnerability to earthquakes and heavy rains (Romero-Lankao, 2010).

The Built Environment: Housing stock, urban form, condition of water and power infrastructures, and changes in urban and ecological services also affect vulnerability. Large, impermeable surfaces and buildings disrupt drainage channels and accelerate run-off (Walsh *et al*., 2005). Damage from floods can be much more catastrophic if drainage or waste collection systems are inadequate to accommodate peak flows (Richardson, 2010; Sosa-Rodriguez, 2010). While infrastructures in many Canadian and US cities are in need of adaptation upgrades (Doyle *et al*., 2008; Conrad, 2010), Mexican cites are additionally faced with infrastructure deficits (Niven *et al*., 2010; Hardoy and Romero Lankao, 2011), and high levels of socio-spatial segregation (Smolka and Larangeira, 2008).

Institutional capacity: Although cities have comparatively higher revenue pools than rural municipalities, barriers to urban adaptation planning persist, including fragmented governance, asymmetries in information access and communication, fiscal constraints to support public services including emergency personnel, and top-down decision making (Carmin *et al*., 2012b; Romero-Lankao *et al*., 2013).

Differences in human and social capital: Cities are better endowed than rural populations with individual and neighborhood assets such as income, education, quality of housing and access to infrastructures and services that offer protection from climate hazards. However, socio-spatial differences in access shape response capacities (Harlan and Ruddell, 2011; Romero-Lankao *et al*., 2013). Social networks, family bonds and other forms of social capital differentially influence individual-level vulnerability (Romero-Lankao *et al*., 2012).

Economic Sensitivity: Climate hazards affect the economic activities and highly-valued physical capital of cities (real estate, transportation infrastructure); some urban areas are particularly exposed to key resource constraints (e.g., water in the US-Mexico Border); others are dependent upon climate-sensitive sectors (e.g., tourism) (Lal *et al*., 2011). Disruptions to production, services and livelihoods, and changes in the costs of raw materials and inputs also impact the economic performance of cities (Hunt and Watkiss, 2011).

Risk Distribution: Class and socio-spatial segregation are key determinants vulnerability. Economic elites are better positioned to access the best land and enjoy the rewards of environmental amenities such as clean air, safe drinking water, open space, and tree shade (Morello-Frosch *et al*., 2002; Harlan *et al*., 2006; Harlan *et al*., 2008; Ruddell *et al*., 2009). Although wealthy sectors are moving into risk prone coastal and forested areas (Collins, 2008), and certain hazards (air pollution) affect both rich and poor alike (Romero-Lankao *et al*., 2013), climate risks tend to be disproportionally borne by the poor or otherwise marginalized populations (Cutter *et al*., 2008; Collins and Bolin, 2009; Romero-Lankao, 2010; Wittrock *et al*., 2011). Marginalized populations are moving to peri-urban areas with inadequate services, a portfolio of precarious livelihood mechanisms, and inappropriate risk-management institutions (Collins and Bolin, 2009; Eakin *et al*., 2010; Monkkonen, 2011; Romero-Lankao *et al*., 2012); (Colton, 2008).

26.8.2.2. Rural Settlements

Geography: Geographic isolation can be a key source of vulnerability, for rural communities, with long commutes to essential services like hospitals, and non-redundant transportation corridors that can be compromised during extreme events (Chouinard *et al*., 2008). Many Indigenous communities are isolated, raising the costs and limiting the diversity of imported food, fuel and other supplies, rendering the ability to engage in subsistence harvesting especially critical for wellbeing (Andrachuk and Pearce, 2010; Hardess *et al*., 2011).

Interactive causes and effects: The legacy of previous and current stresses contributing to rapid population growth or loss, reduced employment, or degradation of local knowledge systems, can increase vulnerability (Brklacich *et al*., 2008; Coles and Scott, 2009; McLeman, 2010). Engagement in export markets presents opportunity but also exposure to economic volatility (Eakin, 2006; Saldaña-Zorilla and Sandberg, 2009), and economic downturns take attention away from climate change adaptation. Many indigenous peoples maintain strong cultural attachment to ancestral lands, and thus are especially sensitive to declines in the ability of that land to sustain their livelihoods and cultural wellbeing (Downing and Cuerrier, 2011).

The Built Environment: Rural physical infrastructure is often inadequate to meet service needs or is in poor condition (McLeman and Gilbert, 2008; Krishnamurthy *et al*., 2011), especially for Indigenous communities (section 26.9, Brklacich *et al*., 2008; Hardess *et al*., 2011; Lal *et al*., 2011). The lack of redundant power and communication services compromises hazard response capacity.

Economic Sensitivity: Rural economies have less diversity, and higher dependence on climate-sensitive sectors (Johnston *et al*., 2008; Lemmen *et al*., 2008; Molnar, 2010), and are sensitive to climate-induced reductions in resource supply and productivity, in addition to direct exposure to climate hazards (Daw *et al*., 2009). Single-sector economic dependence contributes significantly to vulnerability (Cutter *et al*., 2003). Farming and fishing provide both economic and food security, the impacts of climate thus posing a double threat to livelihood (Badjek *et al*., 2010), particularly among women (Bee *et al*., 2013). Inter-related factors affecting vulnerability in forestry and fishing communities include over-harvesting, and the cumulative environmental effects of multiple land use activities (Brklacich *et al*., 2008). Many tourism-based communities are dominated by low-wage, service-based employment (Tufts, 2010), and small businesses that lack resources for emergency planning (Hystad and Keller, 2006; Hystad and Keller, 2008). Non-renewable resource industries are sensitive to power and water supply and transportation disruptions associated with hazards.

Institutional capacity: Small revenue pools translate into fiscal constraints necessary to support public services, including emergency personnel and health care (Lal *et al*., 2011).

Differences in human capital and social capital: North American rural communities have a higher proportion of lower income and unemployed populations and higher poverty than cities (Whitener and Parker, 2007; Lal *et al*., 2011; Skoufias *et al*., 2011). 55% of Mexico's rural residents live in poverty, and the livelihood of 72% of these is in farming (Saldaña-Zorrilla, 2008). U.S. and Canadian rural communities have older populations (McLeman, 2010) and lower education levels (Lal *et al*., 2011). Indigenous communities have lower education levels, and high levels of poverty, but are younger than average populations (Downing and Cuerrier, 2011). The legacy of their colonial history, furthermore, has stripped Indigenous communities of many sources of social and human capital (Brklacich *et al*., 2008; Hardess *et al*., 2011).

Conversely, rural and indigenous community members espouse valuable local and experiential knowledge regarding regional ecosystem services (Nakashima *et al*., 2011).

26.8.3. Projected Climate Impacts on Human Settlements

Urbanization, migration, economic disparity, and institutional capacity are likely to influence future impacts and adaptation to climate change in North America.

Projected SLR is *very likely* to alter regional land development differentially, depending on regional shifts in ocean circulation (U.S. GAO, 2007; Yin *et al*., 2009; Conrad, 2010; Sobel *et al*., 2010; Millerd, 2011), making some areas particularly vulnerable to inundation (Cooper and Sehlke, 2012). SLR also exacerbates vulnerability to extreme events such as hurricanes(Frazier *et al*., 2010).

Temperatures increases are *very likely* lead to additional health hazards in cities. Baseline warmer temperatures in cities are expected to be further elevated by extreme heat events whose intensity and frequency is projected to increase during the 21st century (section 26.2) and impair the health of urban populations (section 26.6), particularly in northern mid-latitude cities (Jacob and Winner, 2009b). Participation in outdoor activities would also increase as a result of projected increases in warm days (Scott and McBoyle, 2007); winter sports face shorter seasons. Projected snowfall declines Canada and the Northeast U.S. would reduce length of winter sport seasons (McBoyle *et al*., 2007; Scott *et al*., 2008b).

Extreme Events, such as intense precipitation, flooding and prolonged dry periods are *likely* to affect settlements on coasts, flood-prone deltas and arid regions (Kirshen *et al*., 2008; Nicholls *et al*., 2008; Richardson, 2010; Weiss *et al*., 2011b). Using an operational hurricane-prediction model (NOAA-GFDL) Bender et al. (2010) project an almost doubling in frequency of category 4 and 5 hurricanes by 2100. By the end of this century, New York City is projected to experience nearly twice as many extreme precipitation days compared to today (A2, mean ensemble of 17 models, (Cayan *et al*., 2010; Ntelekos *et al*., 2010) project increased number and duration of droughts in the southwest U.S., with most droughts expected to last over five years by 2050 (GDFL CM2.1 and CNRM CM3, A2 and B1). Wildfire vulnerability in the southwest has been elevated with peri-urban growth (Collins and Bolin, 2009; Brenkert-Smith, 2010) .

Climate impacts on *Lives and Livelihoods* have been relatively less studied. Projected shifts in forest productivity indicate potential substantial shifts in livelihood options without adaptation. Sohngen and Sedjo (2005) estimate losses from climate change in the Canadian/U.S. timber sector of $1.4 – $2.1 billion per year over the next century. Anticipated future supply reductions in British Columbia as a consequence of the pine beetle outbreak vary from 10 to 62% (Patriquin *et al*., 2007). Forecast substantial declines in suitable habitat for valued tree species in Mexico have been projected (Gómez-Mendoza and Arriaga, 2007; Diaz *et al*., 2011).

Essential Services: Increased occurrence of drought is projected for southwestern U.S./Northern Mexico, the southern Canadian Prairies and central Mexico, combined with projected increases in water demand due to rapid population growth and agriculture (MacDonald, 2010a; Lal *et al*., 2011); (Schindler and Donahue 2006). In the Mexico City Metropolitan Area, due to population growth alone, available water per capita is projected to diminish by 11.2% between 2007 and 2030 (Partida and Anzaldo, 2009). Sea-level rise threatens water and electricity infrastructure with inundation and increasing salinity (Sharp, 2010).

26.8.4. Adaptation

26.8.4.1. Evidence of Adaptation

26.8.4.1.1. What are populations doing? Autonomous adaptation

Individuals in North America have been responding to climate change impacts in several ways, for example by purchasing additional insurance, or reinforcing homes to withstand extreme weather (Simmons and Sutter, 2007; Romero-Lankao *et al*., 2012). When climate change poses significant livelihood impacts, individuals respond by diversifying livelihoods (Newland *et al*., 2008; Rose and Shaw, 2008) or migrating (Black *et al*., 2011). Migration can have maladaptive effects at higher levels: many regions experiencing rapid influxes of in-migrants are also among the most vulnerable to climate change impacts (Hugo, 2011).

The propensity to engage in adaptation is strongly influenced by perceived risks of climate change. Residents of the U.S. stand out in international research as holding lower levels of perceived risk of climate change (AXA Ipsos, 2012), which may limit involvement in household-level adaptation.

26.8.4.1.2. What are authorities doing? Planned adaptation

Overall, leadership in adaptation planning is far more evident locally than at other governance levels (Richardson, 2010; Vasseur, 2011; Vrolijks *et al*., 2011; Carmin *et al*., 2012a; Henstra, 2012). Many local authorities have not yet moved into the implementation stage, and most of the adaptation programs are in the process of problem diagnosis and adaptation planning (Perkins *et al*., 2007; Moser and Satterthwaite, 2009; Romero-Lankao and Dodman, 2011).Climate change policies have been motivated by concerns for local economic or energy security and the desire to play leadership roles (Rosenzweig *et al*., 2010; Anguelovski and Carmin, 2011; Romero-Lankao *et al*., 2013). Some of these constitute "integrated" strategies (New York) (Perkins *et al*., 2007; Rosenzweig *et al*., 2010), and in some cases entail coordinated participation of multiple municipalities (Vancouver) (Richardson, 2010). Sector-specific climate risk management plans have also emerged (e.g., water conservation in Phoenix, US and Regina, Canada; wildfire protection in Kamloops, Canada and Boulder, US). Municipalities affected by the mountain pine beetle have taken many steps toward adaptation (Parkins, 2008), and coastal communities in eastern Canada are investing in saltwater marsh restoration to adapt to rising sea levels (Marlin *et al*., 2007). Green roofs, forest thinning and urban agriculture have all been expanding (Chicago, New York, Kamloops, Mexico City), as have flood protection (New Orleans, Chicago), private and governmental insurance policies (section 26.10, Browne and Hoyt, 2000; Ntelekos *et al*., 2010), safe saving schemes (common in Mexico), air pollution controls (Mexico City), and hazard warning systems (Collins and Bolin, 2009; Coffee *et al*., 2010; Romero-Lankao, 2010; Aguilar and Santos, 2011).

Many municipalities are engaged in problem diagnosis and adaptation planning (Perkins *et al*., 2007; Moser and Ekstrom, 2011; Carmin *et al*., 2012b; Romero-Lankao *et al*., 2013). However, few have reached the implementation stage or are comprehensive in scope; and systematic assessments of vulnerability are rare, particularly in relation to population groups (Vrolijks *et al*., 2011). Surveys of municipal leaders showed adaptation is rarely incorporated into planning, due to lack of resources, information and expertise (Horton and Richardson, 2011), and the prevalence of other issues considered higher priority (United States Government Accountability Office, 2009; Romero-Lankao *et al*., 2013), suggesting the need for state- and federal-level facilitation.

26.8.4.2. Opportunities and Constraints

26.8.4.2.1. Adaptation is path-dependent

Adaptation options are influenced by past settlement patterns and decisions. The evolution of cities as economic hubs, for example, affects vulnerability and resilience (Leichenko, 2011). Urban expansion into mountain, agricultural, protected and otherwise risk-prone areas (Boruff *et al*., 2005; McGranahan *et al*., 2007; Collins and Bolin, 2009; Conrad, 2010) invariably alters regional environments. Development histories foreclose some resilience pathways, such as irreversible overexploitation and degradation of water resources (Mexico City) (Romero-Lankao, 2010). Local cultures can pose barriers to adaptation. While strong attachment to place and occupation may motivate willingness to support incremental change, they have been found to serve as barriers to transformational change (Marshall *et al*., 2012). Those same processes, however, may enhance coping capacity and foster learning and adaptation (Collins and Bolin, 2009; Romero-Lankao, 2010; Aguilar and Santos, 2011; Wittrock *et al*., 2011).

26.8.4.2.2. Institutional capacity

Effective adaptation is influenced by access to resources, and the capacity for institutional-level attention and coordination (Burch, 2010; Romero-Lankao *et al*., 2013). Levels of adaptation knowledge and prioritization can be low among some institutional actors, such as municipal planners (Picketts *et al*., 2012), and industries and governmental actors (Spittlehouse, 2008; Brown, 2009). Research has also shed light on the following attributes:

- *Economic Resources:* Rural communities face limited revenues combined with higher costs of supplying adaptation services (Williamson *et al*., 2008; Posey, 2009). Although large cities tend to have greater fiscal capacity, most do not receive financial support for adaptation (Carmin *et al*., 2012b), yet face the risk of higher economic losses.
- *Information and social capital:* Differences in access and use of information, and capacity for learning and innovation, affect adaptive capacity (Romero-Lankao *et al*., 2013). Information access can be limited, even among environmental planners (Picketts *et al*., 2012). The relationship between trust and participation in support networks (social capital) and adaptive capacity is generally positive, however strong social bonds may support narratives that under-estimate risk (Wolf *et al*., 2010; Romero-Lankao *et al*., 2013).

- *Participation:* Long-term effectiveness of adaptation strategies hinges upon the ability to integrate the needs, concerns, and deliberations of all stakeholders, and complementarity with sustainability goals, involving forward-thinking analysis and continuous learning and adjustment (Swanson *et al.*, 2010). Considering the overlap among impacts and sources of vulnerability, adaptation planning for human settlements demands an integrative approach. Stakeholder involvement lengthens planning time frames, may elicit conflicts, and power relationships can constrain access (Few *et al.*, 2007; Colten *et al.*, 2008). But effective stakeholder engagement has tremendously enhanced adaptation planning, eliciting key sources of information regarding social values, and securing legitimacy (Aguilar and Santos, 2011).
- *Multilevel coordination:* Enhancement of vertical inter-governmental coordination for improved resource delivery is key, especially for rural communities (Brklacich *et al.*, 2008; Brown, 2009; Sander-Regier *et al.*, 2009; Sydneysmith *et al.*, 2010). Integrative planning requires horizontal coordination: careful assessment of the layers involved in land-use planning, emergency responses, housing, health and other sectors and their effects on vulnerability at the municipal, neighbourhood and individual levels (Table 26-1). Traditionally, environmental or engineering agencies are responsible for managing climate issues (e.g., Mexico City, Edmonton and London, Canada), but have neither the decision making power nor the resources to address all the dimensions involved. Adaptation planning requires long-term investments by government, business, grassroots organizations and individuals (e.g., Romero-Lankao, 2007; Croci *et al.*, 2010; Richardson, 2010; Sarah, 2010).

26.8.4.3. Maladaptation, Trade-Offs, and Co-Benefits

Adaptation strategies may introduce trade-offs or maladaptive effects for policy goals in mitigation, industrial development, energy security, and health (Hamin and Gurran, 2009; Laukkonen *et al.*, 2009). Snow-making equipment, for example, mediates snowpack reductions, but is expensive and has high water and energy requirements (Scott *et al.*, 2007). Irrigation and air conditioning have immediate adaptive effects, but are energy-consumptive. Sea walls protect coastal properties, yet negatively affect the structure and functioning of coastal ecosystems (Richardson, 2010).

Conventional sectoral approaches to risk management and adaptation planning undertaken at different temporal and spatial scales have exacerbated vulnerability in some cases (Eakin *et al.*, 2010; Romero-Lankao, 2012)(Doves 2009). Approaches that delegate response planning to residents in the absence of effective knowledge exchange have resulted in maladaptive effects (Friesinger and Bernatchez, 2010).

Other strategies offer potential synergies and co-benefits. Policies addressing air pollution (Harlan and Ruddell, 2011) or housing for the poor (Colten *et al.*, 2008) can often be adapted at low or no cost to fulfill adaptation and sustainability goals simultaneously (Badjek *et al.*, 2010). Efforts to temper declines in production or competitiveness in rural communities could involve mitigation innovations, including carbon sequestration forest plantations (Holmes, 2010). Painting roofs white reduces the effects of heat and lowers energy demand for cooling (Akbari *et al.*, 2009).

Adaptation planning can be greatly enhanced by incorporating region-specific vulnerability information, so socio-economic vulnerabilities can be targeted (Clark *et al.*, 1998). Methods for mapping environmental and socio-economic vulnerability have been improved and widely utilized (Romero-Lankao *et al.*, 2013). Similarly, strategies supporting cultural preservation and subsistence livelihood needs among indigenous peoples would enhance effectiveness (Ford *et al.*, 2010), as would integrating traditional culture with other forms of knowledge, education and economic development (Hardess *et al.*, 2011).

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Box 26-3. Responding to Climate Change in Three North American Cities

With growing populations of 20.5, 14 and 2.3 million people, respectively, the metropolitan areas of Mexico City, New York and Vancouver are facing multiple risks climate change is predicted to aggravate. These risks range from sea level rise, coastal flooding and storm surges in New York and Vancouver to heat waves, heavy rains and associated flooding, air pollution, and heat-island effects in all the three cities (Leon and Neri, 2010; Magana, 2010; Rosenzweig and Solecki, 2010; City of Vancouver, 2012). Many of these risks result not only from long-term global and regional processes of environmental change, but also from local changes in land and water uses and in atmospheric emissions induced by urbanization (Magana, 2010; Romero-Lankao, 2010; Kinney *et al.*, 2011; Solecki, 2012).

Despite the compound risks they are facing, the three cities have shown promise as innovators of climate relevant actions as they have moved to institutionalize their climate agendas. In Mexico City, the Program of Climate Action 2008–2012 (PAC) and the 2011 Law for Mitigation and Adaptation to Climate Change are parts of a larger 15-year "Green Agenda", which focuses mainly on reducing 7 million tonnes of CO2 equivalent between 2008-2012 through mitigation actions, with these efforts accounting for 94.3% of its total budget expenditures between 2008 and 2012 (Romero-Lankao *et al.*, 2012). Similarly, in 2005 New York City's Plan to reduce GHG by 30% from 2005 levels is mitigation centered, as is Vancouver' 2007 Greenest City Plan calling for a 33% reduction in GHG emissions below 2007 levels by 2020. However, mitigation became in 2007 part of New-York's long-term sustainability plan that included adaptation concerns with climate actions intended to protect city's infrastructures and buildings (Solecki, 2012; Ray *et al.*, 2013), while Vancouver launched the first comprehensive municipal adaptation plan in Canada in July 2012. The shifts in focus from mitigation to adaptation have followed as it has become increasingly clear that even if mitigation efforts are wholly successful, some adverse impacts due to climate change are probably unavoidable.

City mayors and other urban actors have often played key roles in launching climate policies. Mayor Michael Bloomberg of New York and Mayor Marcello Ebrard of Mexico City have, respectively, chaired the C40 and World Mayors Council on Climate Change. Scientists, private sector actors and nongovernmental organizations have been of no lesser importance. To take advantage of a broad based interaction between various climate change actors, Mexico City has set up a Virtual Climate Change Center, a boundary organization intended to serve as a repository of knowledge, models and data on climate change impacts, vulnerability and risks (Romero-Lankao *et al.*, 2012). Information sharing by climate change actors has also taken place in New York, where scientists, and insurance and risk management experts have served on the Panel on Climate Change to advise the city on the science of climate change impacts and "protection levels specific to the city's critical infrastructure" (Solecki, 2012): 564).

Notwithstanding these positive pressures, however, climate policies in the three cities are faced with many challenges. Inconsistencies among the three tiers of government approaches (or lack thereof) to climate change are a barrier to effective responses in Vancouver (Burch, 2010). Fragmented governance structures in Mexico City and New York prevent these cities from having jurisdictional control over how their three regionally interdependent states (i.e., Federal District, Mexico and Hidalgo for Mexico City and Connecticut, New Jersey and New York for New York) respond to climate change (Romero-Lankao *et al.*, 2012; Solecki, 2012). There are also conflicts in priorities and objectives between various actors and sectors moving city policy. For instance, authorities in Mexico City are concerned with avoiding growth into risk-prone areas and into conservation areas providing ecosystems-services (Aguilar and Santos, 2011). However, these priorities compete for regulatory space within a policy agenda that is already coping with a very wide range of economic and developmental imperatives (Romero-Lankao *et al.*, 2012). Cultural barriers across stakeholders in the Vancouver region, lack of leadership and of strategies facilitating the effective use of existing resources are notable constraints to effective adaptation (Burch, 2010).

The climate plans of the three cities are far reaching and include mitigation and adaptation strategies that are related to their sustainable development goals. However, few of the proposed actions will result in immediate effects, and instead call for additional planning. This highlights the significant effort that is necessary for comprehensive responses. There are also differences in what the three cities emphasize in their climate action plans. For instance, the three cities differ in their levels of emphasis on infrastructural protection. Mexico City seeks to reduce water and transportation emissions through such actions as improvements in infrastructure and changes in transportation mode-share. Vancouver has prioritized the separation of sanitary and stormwater, yet this adaptation is not expected to be complete until 2050 (City of Vancouver, 2012). It will also take New York much time, money and energy to expand adaptation strategies beyond the protection of water supply, sewer, and wastewater treatment systems to include all essential city infrastructures (Ray *et al.*, 2013);

Climate responses require new types of scientific information at very local scales, e.g., vulnerability analyses, flood risk assessments, health impacts analyses, and these are not always available (Romero-Lankao *et al*., 2012; Ray *et al*., 2013). Little is known, for instance, about how to predict and respond to common and differential levels of risk experienced by different populations within cities. Although some scholarship exists on disparities in household or population level vulnerability and adaptive capacity (Cutter *et al*., 2003; Villeneuve and Burnett, 2003; Douglas *et al*., 2012; Romero-Lankao *et al*., 2013), equity concerns in all three cities have gotten little attention as the cities have focused on reducing emissions (Mexico City), or protecting critical infrastructures (New York and Vancouver). Yet, even when local needs are identified, such as the need to protect higher risk homeless and low-income populations, they are often not addressed in action plans, as risk planning and long term adaptation strategies give way to shorter term priorities and economic imperatives.

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26.9. Federal and State Level Adaptation

Besides adaptations at the city level (section 25.7), governments at the federal, state/provincial, and local levels across North America are developing climate change adaptation plans. These initiatives, which began at the provincial (e.g., Nunavut (Nunavut Department of Sustainable Development, 2003)) and municipal (e.g., Keene, New Hampshire (City of Keene, New Hampshire and ICLEI - Local Governments for Sustainability, 2007)) levels, appear to be preliminary and relatively little has been done to implement specific measures.

26.9.1. Federal Level

All three national governments are addressing adaptation to some extent, with a national strategy and a policy framework (Mexico), a federal policy framework (Canada), and the United States having all federal agencies develop adaptation plans.

In 2005, the Mexican government created the *Inter-Secretarial Commission to Climate Change* (CICC – Comisión Inter-Secretarial de Cambio Climático) to coordinate national public policy on climate change (Comisión Inter-Secretarial de Cambio Climático, 2005; SEMARNAT, 2010; Sosa-Rodriguez, 2013).The government's initiatives are being delivered through the *National Strategy for Climate Change 2007-2012* (Intersecretarial Commission on Climate Change, 2007) and, the *Special Programme on Climate Change 2009-2012*, which identify priorities in research, cross-sectoral action such as developing early warning systems, and capacity development to support mitigation and adaptation actions (Comisión Inter-Secretarial de Cambio Climático, 2009). The *Policy Framework for Medium Term Adaptation* (Consejo Intersecretarial de Cambio Climático, 2010)aims at framing a single national public policy approach on adaptation with a time-horizon up to 2030. The General Law of Climate Change requires state governments to implement mitigation and adaptation actions (Diario Oficial de la Federación, 2012).

Canada is working towards creating a Federal Adaptation Policy Framework intended to mainstream climate risks and impacts into programs and activities to help frame government priorities (Government of Canada, 2011). In 2007, the federal Government made a four-year adaptation commitment to develop six Regional Adaptation Collaboratives (RAC) in provinces across Canada, ranging in size and scope, from flood protection and drought planning, to extreme weather risk management; and assessing the vulnerability of Nunavut's mining sector to climate change (Natural Resources Canada, 2011). In 2011, the federal government renewed financial support for Environment Canada's Climate Change Prediction and Scenarios Program and Canada's Heat Alert and Response System, and provided new funding to create a Climate Adaptation and Resilience Program for Aboriginals and Northerners, and to finance the integration of adaptation into National Codes and Standards (Environment Canada, 2011).

The U.S. government embarked in 2009 on a federal government wide effort to have all federal agencies address adaptation; 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 (The White House, 2009; Bierbaum *et al.*, 2012). The U.S. Government provides technical and information support for adaptation by non-federal actors, but does not provide direct financial support for adaptation (Parris *et al.*, 2010).

Some federal agencies took steps to address climate change adaptation prior to this broader interagency effort. In 2010, the U.S. Department of Interior created Climate Science Centers to integrate climate change information and management strategies in eight regions and 21 Landscape Conservation Cooperatives (Secretary of the Interior, 2010), while the U.S. Environmental Protection Agency's Office of Water developed a climate change strategy (U.S. Environmental Protection Agency National Water Program, 2011).

26.9.2. State and Provincial Levels

A number of states and provinces in all three countries have developed adaptation plans. For example, Ontario's 2011-2014 adaptation strategy and action plan identifies 37 measures, including requiring that building codes be revised to increase resilience and increase water and energy conservation (Government of Ontario, 2011). Quebec updated their plan which covers a number of managed sectors and ecosystems (Government of Quebec, 2012). British Columbia is modernizing its *Water Act* to alter water allocation during drought to reduce agricultural crop, livestock loss and community conflict, while protecting aquatic ecosystems (British Columbia Ministry of the Environment, 2010).

In the U.S. California was the first state to publish an adaptation plan calling for a 20% reduction in per capita water use by 2020 (California Natural Resources Agency, 2009). Maryland first developed a plan on coastal resources and then broadened it to cover human health, agriculture, ecosystems, water resources, and infrastructure (Maryland Commission on Climate Change Adaptation and Response Working Group, 2008; Maryland Department of the Environment on behalf of the Maryland Commission on Climate Change, 2010). The State of Washington is addressing environment, infrastructure, and communities; human health and security; ecosystems, species, and habitat; and natural resources (Washington State Built Environment: Infrastructure & Communities Topic Advisory Group (TAG), 2011; Washington State TAG 4 Natural Resources Working Lands and Waters, 2011; Washington State Topic Advisory Group (TAG) Report- TAG 2 Human Health and Security, 2011; Washington State Topic Advisory Group 3 Species, Habitats and Ecosystems, 2011).

In Mexico, Veracruz, Mexico City, Nuevo León, Guanajuato, Puebla, Tabasco, and Chiapas, have all developed their *State Programmes for Climate Change Action* (Programas Estatales de Acción ante el Cambio Climático - PEACC), while Baja California Sur, Hidalgo, and Campeche are in the final stage and 17 states are still in the planning and developing stage (Instituto de Ecología del Estado de Guanajuato, 2011). The proposed adaptation actions focus mainly on: 1) reducing physical and social vulnerability of key sectors and populations; 2) conservation and sustainable management of ecosystems, biodiversity, and ecosystem services; 3) developing risk management strategies; 4) strengthening water management; 5) protecting human health, and; 6) improving current urban development strategies, focusing on settlements and services, transport and land use planning.

26.9.3. Barriers to Adaptation

Of the three national governments, only Mexico requires that states develop adaptation plans. Most adaptation activities have only involved planning for climate change and few measures have been implemented (Preston *et al.*, 2010; Bierbaum *et al.*, 2012).

Even though Canada and the U.S. are relatively well-endowed in their capacity to adapt, there are significant constraints on adaptation (Chapter 16), with financing being a significant constraint in all three countries(Carmin *et al.*, 2012a). Barriers include legal constraints (e.g., Jantarasami *et al.*, 2010) lack of coordination across different jurisdictions (Smith *et al.*, 2009; National Research Council, 2010; INECC-SEMARNAT, 2012), leadership (Smith *et al.*, 2009; Moser and Ekstrom, 2010), and divergent perceptions about climate change (Bierbaum *et al.*, 2012). Although obtaining accurate scientific data was ranked less important by (Carmin *et al.*, 2012a), an important constraint is lack of access to scientific information and capacity to manage and use it (Moser and Ekstrom, 2010; INECC-SEMARNAT, 2012). Adaptation activities in the U.S. tend to address hazards and propose adaptations that tend to protect current activities rather than facilitate long term change. In addition, the adaptation plans generally do not attempt to increase adaptive capacity (Eakin and Patt, 2011).

26.10. Key Multi-Sectoral Risks, Uncertainties, Knowledge Gaps, and Research Needs

26.10.1. Key Multi-Sectoral Risks

We close this chapter with our assessment of key current and future regional risks (Figure 26-6). These figures illustrate how *relative* risks within a sector can change based on increases in the magnitude and rate of climate change and adaptation levels. However, the assignment of *absolute* risk by sector/system and relative risk across sectors/systems and regions should be interpreted with much caution for different reasons. Risks in *terrestrial ecosystems* and *coastal systems* lend themselves better to *predictions* based on models that mix historical and theoretical information. That is not the case with the complexity of key risks in such systems and sectors as water resources and management, food security, and urban and rural settlements, where differences in the severity of climate risks are likely to be strongly influenced by context-specific societal and environmental factors and processes (e.g., population and economic growth, governance, land use change, etc.) whose future trajectories are inherently unpredictable, or unknown. That can be the reason why it was harder for team authors to assign risk levels in the areas of human security, livelihoods and poverty.

[INSERT FIGURE 26-6 HERE
Figure 26-6: Estimated climate risk to key sectors and systems in North America, for different time frames (2030-2040 and 2080-2100), under two levels of global warming (2°C and 4°C), and diverse assumptions about anticipated adaptation. Levels of risk and levels of anticipated adaptation are differentiated by colored shading and ranges from low to high. They represent the judgment of North American individual authors who have different approaches or "ways of knowing" and assessing risks, and realize that generalizations over an area as heterogeneous as North America can be difficult to interpret.]

This figure assigns a single score to sectors and systems that contain a wide array of risks amongst their components. Consider for example agriculture. Although projected changes in temperature, precipitation and extreme events are predicted to result in notable productivity declines in major North American crops, vulnerability to climate varies considerably depending on the extent to which farmers and communities have access to financial resources, technology, institutional support mechanisms and social networks. Risk in rural and urban settlements and economy sectors can vary considerably depending on context-specific social and physical factors faced by different communities, individuals, and firms. Even in biophysical coastal and terrestrial ecosystems, vulnerability varies widely across individual species and landscapes. Furthermore, the rate of change matters in ecosystems (e.g., 2C by 2040 is more risky than 2C by 2080). In short the judgments on risk in this figure are intended to apply to each sector as a whole, but should *not* be interpreted to mean that all components of the sector face the same level of risk.

A further key consideration is that the judgments about risk conveyed by these figures were made by experts living under current socio-economic conditions, not being able as such to fully anticipate potential future changes. Yet over the course of the 21st century, socioeconomic conditions will very likely change considerably for many sectors, systems and places. The dynamics of wealth generation and distribution, technological innovations, institutions, even culture, can substantially affect what level of risk can be absorbed by the North American systems and sectors considered in Figure 26-6. Under the conditions and estimations of risk depicted in the figure it is, hence, highly likely that in the near term (*the era of climate responsibility*), risks associated with committed climate changes can be managed primarily through adaptation actions. However, current mitigation actions can help reduce risks during the second half of the century (*the era of climate options*).

26.10.2. Uncertainties, Knowledge Gaps, and Research Needs

The literature on climate impacts, adaptation and vulnerability in North America has grown considerably, as has the diversity of sectors and topics covered (e.g., urban and rural settlements, food security, and adaptation at local, state and national levels). However, limitations in the topical and geographical scope of this literature are still a challenge (e.g., more studies have focused on insurance than on economic sectors such as industries, construction and transportation). It is also challenging to summarize results across many studies and identify trends in the literature when there are differences in methodology, theoretical frameworks and causation narratives (e.g., between outcome and contextual approaches) making it hard to compare "apples to oranges" (Romero-Lankao *et al*., 2012) While the US and Canada have produced large volumes of literature, Mexico lags well behind. It was, therefore, difficult to devote equal space to observed and projected impacts, vulnerabilities and adaptations in Mexico in comparison with its Northern neighbors. With its large land area, population and important, albeit understudied, climate change risks and vulnerabilities, more climate change research focusing on Mexico is direly needed.

The literature on North America tends to be dominated by sector level analyses. Yet, climate change interacts with other physical and social processes to create differential risk and impact levels. These differences are mediated by context-specific physical and social factors shaping the vulnerability of exposed systems and sectors. Furthermore, while studies often focus on isolated sectorial effects, impacts happen in communities, socio-ecologic systems and regions, and shocks and dislocations in one sector or region often affect other sectors and regions due to social and physical interdependencies. This point is illustrated by our border region and wildfire boxes and the human settlements section, which discuss place-based impacts, vulnerabilities and adaptations. Unfortunately, literature using placed-based or integrated approaches to these complexities is limited. Indeed although in early drafts the authors of this chapter attempted to put more emphasis on place-based analysis and comparisons, the literature was inadequate to support such an effort. The IPCC includes chapters on continents and large regions to make it possible to assess how multiple climate change impacts can affect these large areas. However, this macro view gives insufficient detail on context specific local impacts and risks, missing the on-the-ground reality that the effects of climate change are and will be experienced at much smaller scales, and those smaller scales are often where meaningful mitigation and adaptation actions can be generated. In order to give local actors relevant information on which to base these local actions, more research is needed to better understand the local and regional effects of climate change across sectors.

Frequently Asked Questions

FAQ 26.1: What makes North America especially unique compared with other continents when it comes to climate vulnerabilities?

North America is unique in the very broad diversity of geography, climate, economic development, social fabric and governance systems which can be found across its broad landmass, and result in different vulnerabilities and capacities to adapt across sectors and regions. Layered on top of this broad diversity is a similarly broad range of climate trends and projections. For example rapid observed and projected further warming of northern NA will lead to major changes in transportation, agriculture, and native livelihoods. Meanwhile, strong drying trends in the western US and Mexico are leading to major stresses on water supplies, agriculture, and ecological services.

FAQ 26.2: Will changing patterns of precipitation be experienced in NA and if so, in what ways?

Future projections over NA suggest increases in annual precipitation in Canada and Alaska. However decreases in the southwestern US and much of Mexico are projected. These average trends will be accompanied by increasing intensity of precipitation events along with longer, more intense periods of draught. Thus, variability in precipitation appears to be a hallmark of future climate in NA. Extreme storm events can have significant impacts on local infrastructure and human health when they exceed the intensity for which these systems have been developed over many decades. The large concentration of human and infrastructure resources in the Gulf of Mexico and other coastal regions can exacerbate this vulnerability.

FAQ 26.3: What sectors/regions are more vulnerable? What factors/drivers contribute to a vulnerable situation?

- *Water supplies and quality in many regions*: Runoff throughout most of Mexico, except the south, much of the western United States and southwestern Canada is likely to decrease. These areas are already facing stress from limited water supply and lower future runoff is likely to result in increased competition for water supplies, decreased agricultural production, and harm to aquatic ecosystem.
- *Agriculture in Mexico*, particularly among smallholders: Higher temperatures, a decrease in runoff, and lower soil moisture, which are all considered to be likely for many agricultural-producing areas of Mexico, will likely decrease agricultural production. Only a small proportion of cultivated land is irrigated, furthermore, and the availability of insurance to small-holders in particular is limited. This risks reducing food security, and increasing social instability and migration. Mention something about the wet tropical south
- *Many ecosystems*: In particular, wildfire and pest outbreaks have increased in North America and both of these trends have been linked to climate change. Forest ecosystems, forest-based industries, and human settlements have been impacted negatively by recent wildfire and pest events. Forecasts indicating increasing frequency and intensity of both processes suggest a high likelihood for further reductions in biodiversity, loss of habitat, decreases in ecosystem services, challenges for forest-based industries, and increased economic and health consequences for local communities

FAQ 26.4: What lessons can be drawn from existing adaptation actions on the factors shaping effective responses?

Different economic and demographic sectors and tiers of government are starting to assess their climate change vulnerabilities and designing adaptation programs. Many responses are in diagnosis and planning stage and have not yet moved into the implementation.

Engaging stakeholders in adaptation has proved effective in gaining legitimacy for public decisions and helping capture local realities. The use of scientific information in participatory exercises has also been crucial. However, potential issues might arise: delays in decision making; tensions and conflicts among stakeholder groups embedded in power relationships that can constrain the access of the general population to decision making processes. In addition, adaptation may be constrained by a general unwillingness to address long-term changes (e.g., many decision makers have relatively short term planning and management horizons).

Adapting 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 sectoral and spatial layers involved (e.g., land-use planning, emergency responses, housing, and health). Often, environmental or engineering agencies are responsible for managing climate issues, but do not have the decision making power nor the resources available to address all the dimensions involved. Adaptation requires not only shorter term actions, but also longer term measures and perspectives by the different tiers of governmental, businesses, grassroots organizations and individuals.

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Table 26-1: Dimensions of vulnerability. Source: Romero-Lanka, 2012.

Climate Hazards	**System/Sector of concern**	**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	Infrastructures	Ethnicity
Heat waves	Economic sector	Air & water quality	Services (water, waste)	Migration status
Storm-surge	Demographic group	Economic disruptions	Housing	Income
	Infrastructure	Migration	Social capital	Education
	Transport	Financial losses	Economic base	Health conditions
	Hinterland	Livelihoods	Policy (emergency) response	Knowledge, experience
	Ecosystem services		Governance	Savings
				Insurance
				Risk perceptions

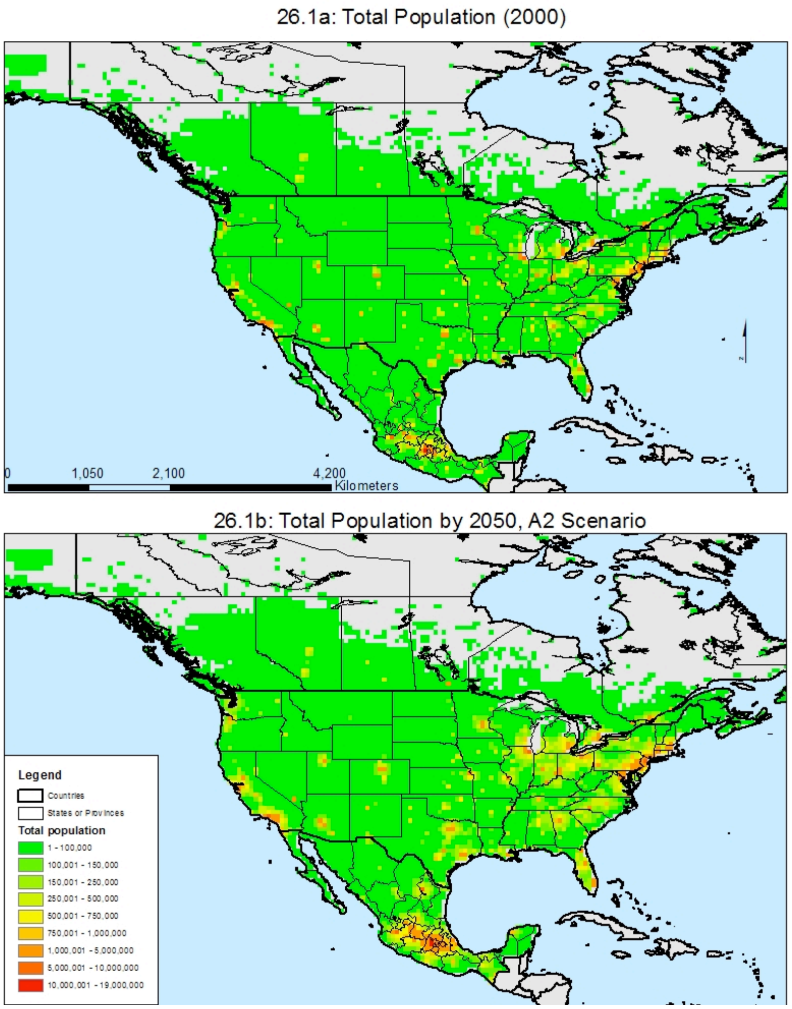

Figure 26-1: Current and future populations in North America. While concentrations of growing populations, infrastructures, and sectors in urban areas can be a source of risk, geographic isolation of rural populations can be a source of sensitivity that is aggravated by high dispersion levels. Source: Lutz, 2007.

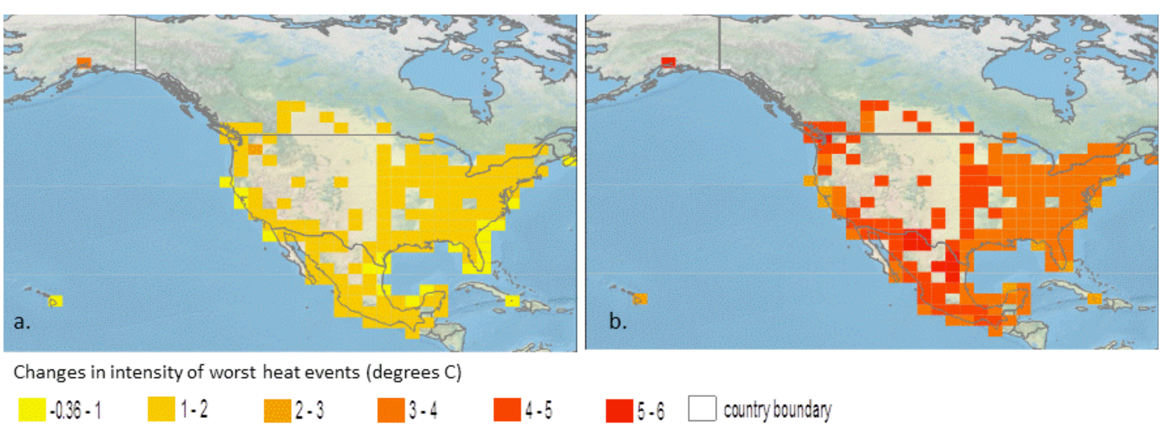

Figure 26-2: Projected changes in the intensity of the worst heat events, as simulated by CLMU for urban grid cells: a) near term (2020-2039) relative to present-day climate (1980-1999); b) end of the 21st century (2080-2099) relative to present-day climate (1980-1999). Source Wilhelmi et al. (forthcoming).

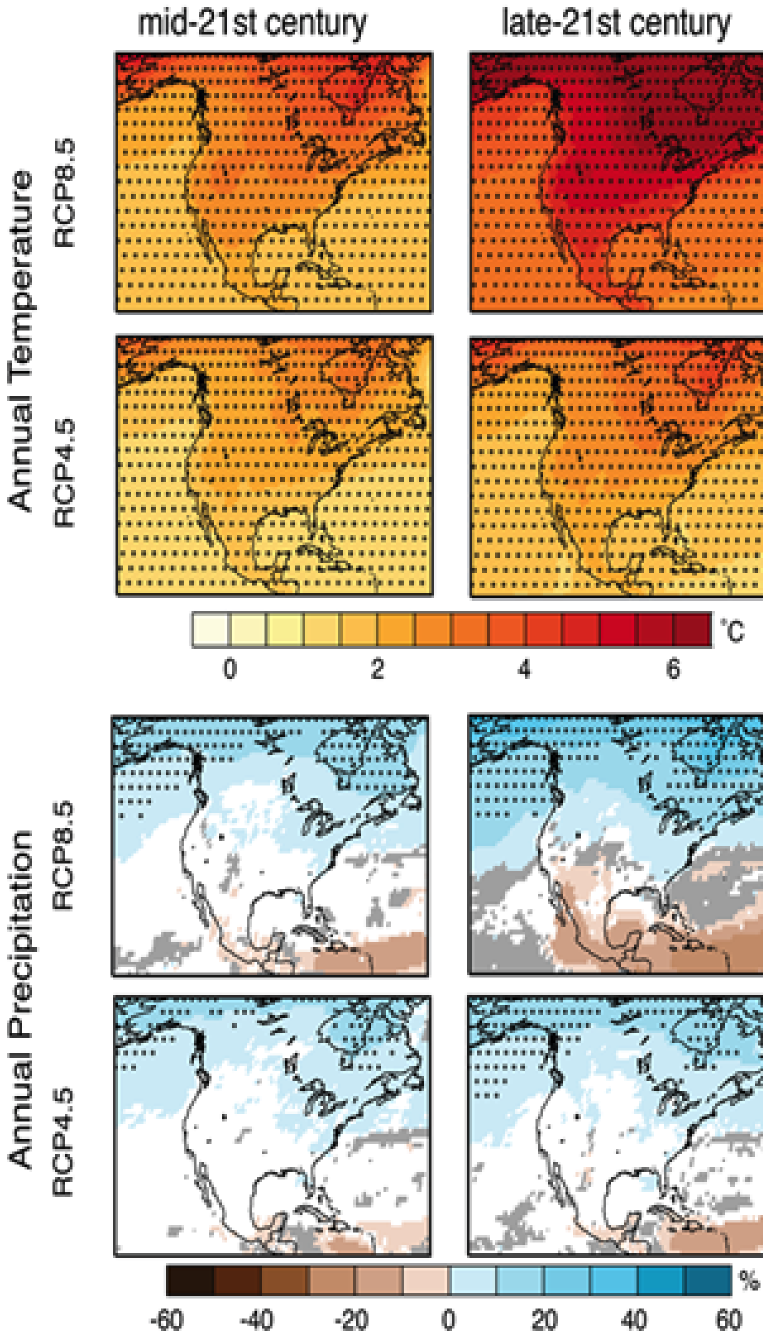

Figure 26-3: Changes in annual temperature and precipitation. White indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.

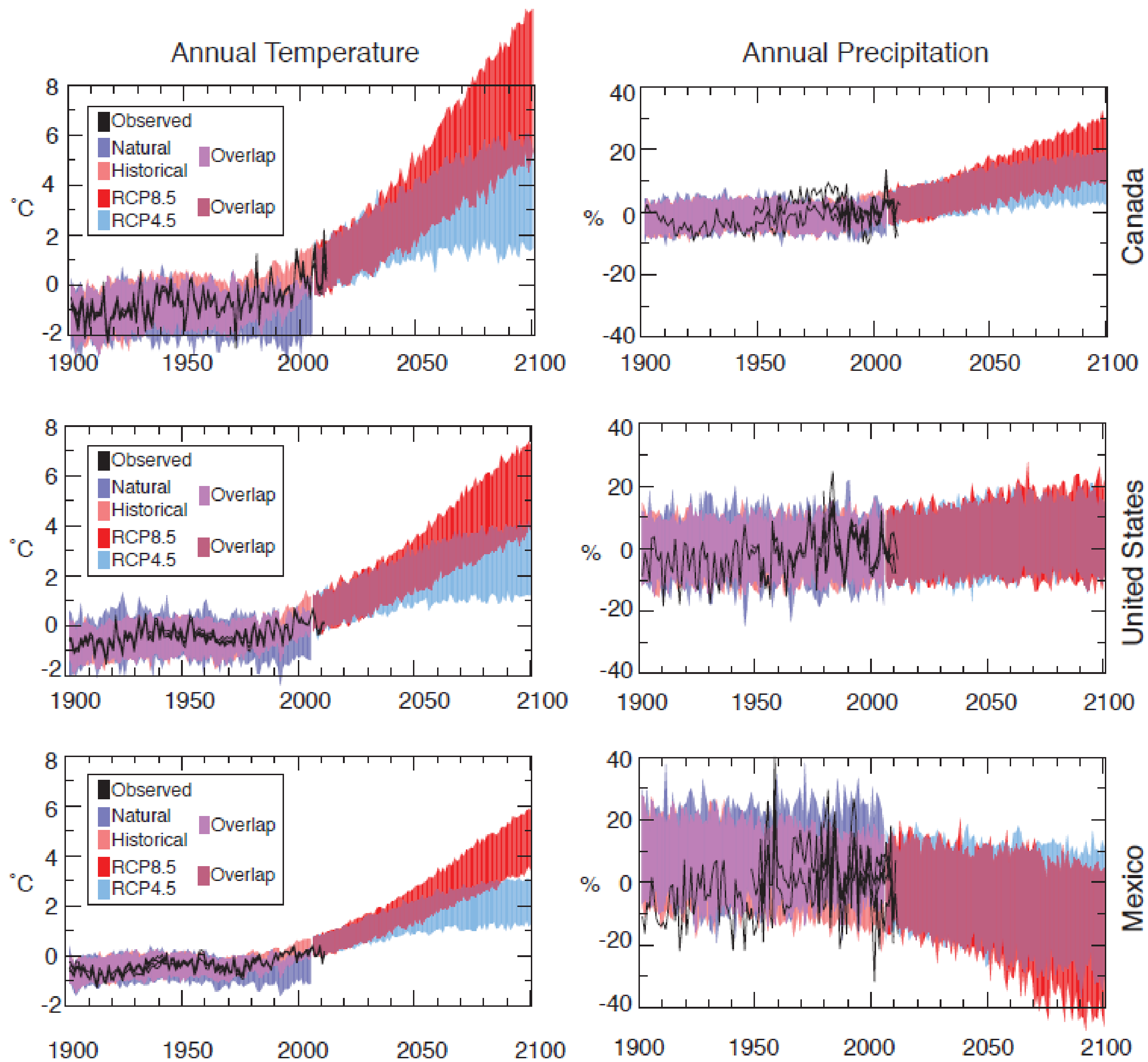

Figure 26-4: Observed and simulated variations in past and projected future annual average precipitation and temperature over land areas of Canada, the contiguous United States, and Mexico. Black lines show several estimates from observational measurements. Shading denotes the 5-95 percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (68 simulations), historical changes in "natural" drivers only (30), the "RCP4.5" emissions scenario (68), and the "RCP8.5" (68). Data are anomalies from the 1986-2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Box 21-3.

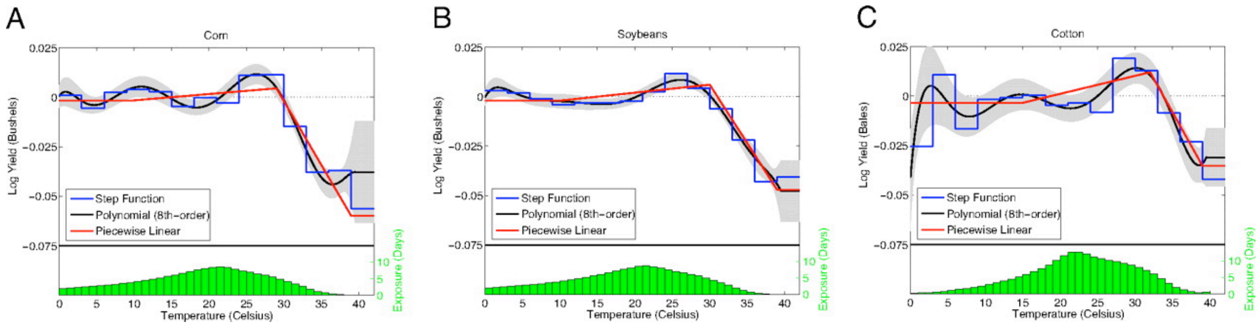

Figure 26-5 Nonlinear relation between temperature and yields. Source: Schlenker, 2009.

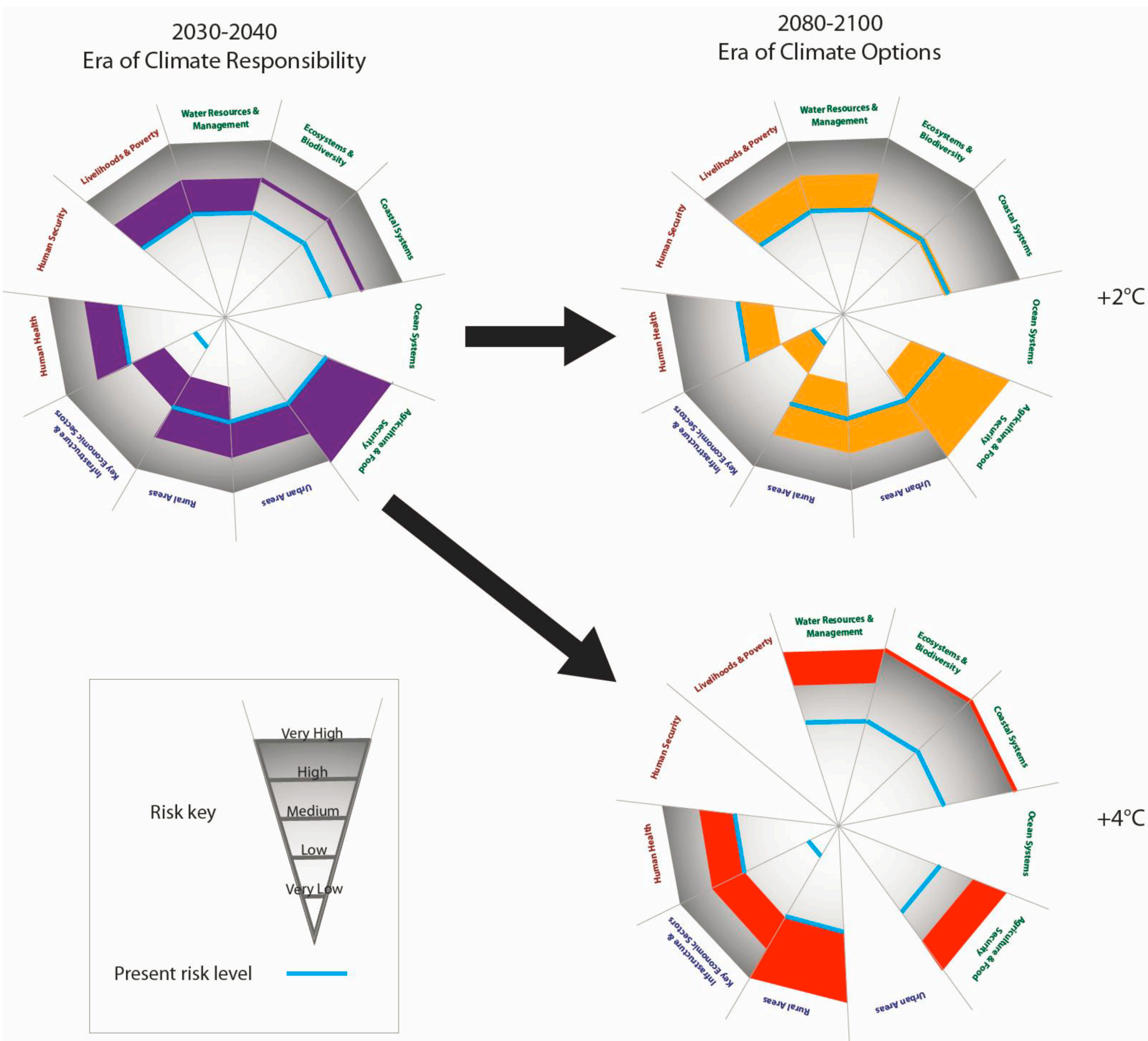

Figure 26-6: Estimated climate risk to key sectors and systems in North America, for different time frames (2030-2040 and 2080-2100), under two levels of global warming (2°C and 4°C), and diverse assumptions about anticipated adaptation. Levels of risk and levels of anticipated adaptation are differentiated by colored shading and ranges from low to high. They represent the judgment of North American individual authors who have different approaches or "ways of knowing" and assessing risks, and realize that generalizations over an area as heterogeneous as North America can be difficult to interpret.