Chapter 26. North America

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Executive Summary

Overview

North America's climate has changed and some societally-relevant changes have been attributed to anthropogenic causes (*very high confidence*) [Figure 26-1]. Recent climate changes and individual extreme events demonstrate both impacts of climate-related stresses and vulnerabilities of exposed systems (*very high confidence*) [Figure 26-2]. Observed climate trends in North America include an increased occurrence of severe hot weather events over much of the US, decreases in frost days, and increases in heavy precipitation over much of North America (*high confidence*). [26.2.2.1] The attribution of observed changes to anthropogenic causes has been established for some climate and physical systems (e.g., earlier peak flow of snowmelt run-off and declines in the amount of water stored in spring snowpack in snow-dominated streams and areas of western United States and Canada (*very high confidence*) [Figure 26-1]. Evidence of anthropogenic climatic influence on ecosystems, agriculture, water resources, infrastructure, and urban and rural settlements is less clearly established, though, in many areas, these sectors exhibit substantial sensitivity to climate variability (*high confidence*) (26.3.1; 26.3.2; 26.4.2.1; 26.4.2.2; 26.4.3.1; Box 26-3; 26.5.1; 26.7.1.1; 26.7.2; 26.8.1; Figure 26-2).

Many climate stresses that carry risk – particularly related to severe heat, heavy precipitation and declining snowpack – will increase in frequency and/or severity in North America in the next decades (*very high confidence*). Global warming of approximately 2°C (above the pre-industrial baseline) is *very likely* to lead to more frequent extreme heat events and daily precipitation extremes over most areas of North America, more frequent low snow years, and shifts towards earlier snowmelt runoff over much of the western US and Canada [26.2.2.2]. Together with climate hazards such as higher sea levels and associated storm surges, more intense droughts, and increased precipitation variability, these changes are projected to lead to increased stresses to water, agriculture, economic activities and urban and rural settlements (high confidence) [26.3.2.1-26.3.2.4; 26.5.2; 26.7.1.2; 26.8.3]. Global warming of approximately 4°C is *very likely* to cause larger changes in extreme heat events, daily-scale precipitation extremes and snow accumulation and runoff, as well as emergence of a locally-novel temperature regime throughout North America [26.2.2.2]. This higher level of global temperature change is *likely* to cause decreases in annual precipitation over much of the southern half of the continent and increases in annual

precipitation over much of the northern half of the continent [26.2.2.2]. The higher level of warming would present additional and substantial risks and adaptation challenges across a range of sectors (*high confidence*). [26.3.3, 26.5.2, 26.6.2, 26.7.2.2, 26.8.3]

We highlight below key findings on impacts, vulnerabilities, projections, and adaptation responses relevant to specific North American sectors: ecosystems, water, agriculture, human health, urban and rural settlements, infrastructure and the economy. We then highlight challenges and opportunities for adaptation, and future risks and adaptive capacity for three key climate-related risks.

Sector-Specific Climate Risks and Adaptation Opportunities

North American ecosystems are under increasing stress from rising temperatures, CO_2 concentrations, and sea-levels, and are particularly vulnerable to climate extremes (*very high confidence*). Climate stresses occur alongside other anthropogenic influences on ecosystems, including land-use changes, non-native species, and pollution, and in many cases will exacerbate these pressures (*very high confidence*). [26.4.1; 26.4.3]. Evidence since the Fourth Assessment Report highlights increased ecosystem vulnerability to multiple and interacting climate stresses in forest ecosystems, through wildfire activity, regional drought, high temperatures, and infestations (*medium confidence*) [26.4.2.1; Box 26-2]; and in coastal zones due to increasing temperatures, ocean acidification, coral reef bleaching, increased sediment load in run-off, sea level rise, storms, and storm surges (*high confidence*) [26.4.3.1]. In the near term, conservation and adaptation practices can buffer against climate stresses to some degree in these ecosystems, both through increasing system resilience, such as forest management to reduce vulnerability to infestation, and in reducing co-occurring non-climate stresses, such as careful oversight of fishing pressure (*medium confidence*) [26.4.4].

Water resources are already stressed in many parts of North America due to non-climate change anthropogenic forces, and are expected to become further stressed due to climate change (*high confidence*) [26.3, 26.3.1]. Decreases in snowpacks are already influencing seasonal streamflows (*high confidence*) [26.3.1]. While indicative of future conditions, recent floods, droughts, and changes in mean flow conditions cannot yet be attributed to climate change (*medium to high confidence)* [26.3.1, 26.3.2]. The 21st century is projected to witness decreases in water quality and increases in urban drainage flooding throughout most of North America under climate change as well as a decrease in instream uses such as hydropower in some regions (*high confidence)* [26.3.2.2, 26.3.2.3, 26.3.2.4]. Additionally, there will be decreases in water supplies for urban areas and irrigation in North America except in general for southern tropical Mexico, northwest coastal US, and west coastal Canada (*high to medium confidence*, 26.3.2.1). Many adaptation options currently available can address water supply deficits; adaptation responses to flooding and water quality concerns are more limited (*medium confidence*) [26.3.3].

Effects of temperature and climate variability on yields of major crops have been observed (*high confidence*) [25.5.1]. Projected increases in temperature, reductions in precipitation in some regions, and increased frequency of extreme events would result in net productivity declines in major North American crops by the end of the 21st Century without adaptation, although the rate of decline varies by model and scenario, and some regions, particularly in the north, may benefit (*very high confidence*) [26.5.2]. Given that North America is a significant source of global food supplies, projected productivity declines here may affect global food security (*medium confidence*)**.** At 2°C, adaptation has high potential to off-set projected declines in yields for many crops, and many strategies offer mitigation co-benefits; but effectiveness of adaptation would be reduced at 4°C *(high confidence)*. [26.5.3] Adaptation capacity varies widely among producers, and institutional support—currently lacking in some regions—greatly enhances adaptive potential (*medium confidence*) [26.5.4].

Human health impacts from extreme climate events have been observed, although climate change-related trends and attribution have not been confirmed to-date. Extreme heat events currently result in increases in mortality and morbidity in North America (*very high confidence*), with impacts that vary by age, location and socioeconomic factors (*high confidence*) [26.6.1.2]. Extreme coastal storm events can cause excess mortality and morbidity, particularly along the east coast of the United States, and the gulf coast of both Mexico and the United States (*high confidence*) [26.6.1.1]. A range of water-, food-, and vector-borne infectious diseases, air pollutants, and airborne pollens are influenced by climate variability and change (medium confidence) [26.6.1.3, 26.6.1.4, 26.6.1.5, 26.6.1.6]. Further climate warming in NA will impose stresses on the health sector through more severe extreme events such as heat waves and coastal storms, as well as more gradual changes in climate and CO_2 levels. [26.6.2] Human health impacts in NA from future climate extremes can be reduced by adaptation measures such as targeted and sustainable air conditioning, more effective warning and response systems, enhanced pollution controls, urban planning strategies, and resilient health infrastructure (*high confidence*) [26.6.3].

Observed impacts on livelihoods, economic activities, infrastructure and access to services in North American urban and rural settlements have been attributed to sea level rise, changes in temperature and precipitation, and occurrences of such extreme events as heat waves, droughts and storms (high confidence) [26.8.2.1]. Differences in the severity of climate impacts on human settlements are strongly influenced by context-specific social and environmental factors and processes that contribute to risk, vulnerability and adaptive capacity such as hazard magnitude, populations access to assets, built environment features and governance (high confidence) [26.8.2.1 and 26.8.2.2]. 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, human and capital risks are highly concentrated in some highly exposed urban locations, while in rural areas, geographic isolation and institutional deficits are key sources of vulnerability. Among the most vulnerable are indigenous peoples due to their complex relationship with their ancestral lands and higher reliance on subsistence economies, and those urban centers where high concentrations of populations and economic activities in risk-prone areas combine with several socio-economic and environmental sources of vulnerability (high confidence) [26.8.2.1 and 26.8.2.2]. Although larger urban centers would have higher adaptation capacities, future climate risks from heat waves, droughts, storms and sea level rise in cities would be enhanced by high population density, inadequate infrastructures, lack of institutional capacity and degraded natural environments (high agreement, medium evidence) [26.8.3].

Much of North American infrastructure is currently vulnerable to extreme weather events and, unless investments are made to strengthen them, would be more vulnerable to climate change (*medium confidence*). Water resources and transportation infrastructure are in many cases deteriorating, thus more vulnerable to extremes than strengthened ones (*high confidence*). Extreme events have caused significant damage to infrastructure in many parts of North America; risks to infrastructure are particularly acute in Mexico but are a big concern in all three countries (*high confidence*) [26.7].

Most sectors of the North American economy have been affected by and have responded to extreme weather, including hurricanes, flooding, and intense rainfall (*high confidence*) (Figure 26-2). Despite a growing experience with reactive adaptation, there are few examples of proactive adaptation anticipating future climate change impacts, and these are largely found in sectors with longer-term decision-making, including energy and public infrastructure. Knowledge about lessons learned and best adaptive practices by industry sector are not well-documented in the published 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 thaw – are an emerging concern for some sectors, with large regional variation in awareness and adaptive capacity (*medium confidence*).

Adaptation Responses

Adaptation – including through technological innovation, institutional strengthening, economic diversification, and infrastructure design – can help to reduce risks in the current climate, and to manage future risks in the face of climate change (medium confidence) [26.8.4; 26.9.2]. There is increasing attention to adaptation among planners at all levels of government but particularly at the municipal level, with many jurisdictions engaging in assessment and planning processes. These efforts have revealed the significant challenges and sources of resistance facing planners at both the planning and implementation stages, particularly the adequacy of informational, institutional, financial and human resources, and lack of political will (*medium confidence*) [26.8.4.2; 26.9.3]. Specific strategies introduced into policy to date tend to be incremental rather than transformational. Fiscal constraints are higher for Mexican jurisdictions and sectors than for Canada or the US. The literature on sectoral-level adaptation is stronger in the areas of technological and engineering adaptation strategies than in social, behavioral and institutional strategies. Adaptation actions have the potential to result in synergies or tradeoffs with mitigation and other development actions and goals (*high confidence*) [26.8.4.2; 26.9.3].

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 United States (US). 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 differ considerably across the continent depending on geography, scale, hazard, socio-ecological systems, ecosystems, demographic sectors, cultural values and institutional settings. This chapter seeks to take account of this diversity and complexity as it affects and is projected to affect vulnerabilities, impacts, risks and adaptation across North America.

No single chapter would be adequate to cover the range and scope of the literature about climate change vulnerabilities, impacts and adaptations in our three focus countries. (Interested readers are encouraged to review the following reports: (Instituto Nacional de Ecología y Cambio Climático, 2012a; National Climate Assessment Development Advisory Committee, 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 key economic sectors and services (section 26.7). We use a comparative and place-based 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 subnational 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, physical and socioeconomic process (e.g., decadal climatic oscillation, droughts, wildfires land-use, and forest management) 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 one of 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 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 Chapter 13 of the Fourth IPCC assessment focused on Mexico (Magrin *et al*., 2007)*,* and Chapter 14 on Canada and the US (Field *et al*., 2007). It focuses on observed and projected impacts, vulnerabilities and risks as well as on adaptation practices and options and highlights areas of agreement and difference between the AR4's two chapters and our consolidated North American chapter.

Observed impacts and processes associated with vulnerability. Both chapter 14 [14.2] and our chapter (Figure 26-2) find that over the past decades, economic damage from severe weather has increased dramatically. Our chapter confirms that although Canada and the US have considerably more adaptive capacity than Mexico, their vulnerability depends on the effectiveness and timing of adaptation and the distribution of capacity, which vary geographically and between sectors. [14.2.6; 14.4; 14.5] [26.2.2; 26.8.2]

Chapters 13 and 14 did not assess impacts, vulnerabilities and risks in urban and rural settlements, but rather assessed literature on *future risks* in the following sectors:

- *Ecosystems*: Both AR4 and our chapter find that ecosystems are under increased stress from increased temperatures, climate variability and other climate stresses (e.g., sea level rise and storm-surge flooding), and that these stresses interact with developmental and environmental stresses (e.g., as salt intrusion, pollution, population growth and the rising value of infrastructure in coastal areas) [13.4.4; 14.2.3; 14.4.3]. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections would alter ecosystem structure, function and services in terrestrial ecosystems [14.2; 14.4]. Both reports show that dry soils and warm temperatures are associated with increased wildfire activity and insect outbreaks in Canada and the US [14.2; 14.4; 26.4.2.1].
- *Water resources:* AR4 projects millions in Mexico to be at risk from the lack of adequate water supplies due to climate change[13.4.3]; our chapter, however, finds that water resources are already stressed by non-climatic factors, such as population pressure that will be compounded by climate change [26.3.1]. Both reports find that in the US and Canada rising temperatures would diminish snowpack and increase evaporation [26.2.2.1], thus affecting seasonal availability of water [14.2.1; 26.3.1]. The reports also agree that these effects will be amplified by water demand from economic development, agriculture and population growth, thus imposing further constraints to over-allocated water resources and increasing competition among agricultural, municipal, industrial and ecological uses [14.4.1; 14.4.6; 26.3.3]. Both agree water quality will be further stressed [14.4.1; 26.3.2.2; 13.4.3]. There is more information available now on water adaptation than in AR4 [14.5.1; 26.3.3; 13.5.1.3], and is possible to attribute changes in extreme precipitation, snowmelt and snowpack to climate change [26.3.1; 14.2.1; 13.2.4]
- *Agriculture*: The AR4 noted that while increases in grain yields in the US and Canada are projected by most scenarios [14.4.4], in Mexico the picture is mixed for wheat and maize, with different projected impacts depending on scenario used [13.4.2]. Research since the AR4 has offered more cautious projections of yield change in North America due to shifts in temperature and precipitation, particularly by 2100; and significant harvest losses due to recent extreme weather events have been observed [26.5.1]. Furthermore, our chapter reports on recent research that underscores the context specific nature of adaptation capacity and of institutional support and shows that these factors, which greatly enhance adaptive potential, are currently lacking in some regions [26.5.3].
- *Health*: AR4 focused primarily on a set of future health risks. These include changes in the geographical distribution and transmission of diseases such as dengue [13.4.5]; increases in respiratory illness, including exposure to pollen and ozone [14.4] and in mortality from hot temperatures and extreme weather in Canada and the US. AR4 also projects that climate change impacts on infrastructure and human health in cities of Canada and the US would 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]. Without increased investments in measures such as early warning and surveillance systems, air conditioning, and access to health care, hot temperatures and extreme weather in Canada and the US are predicted to result in increased adverse health impacts [14.4; 14.5]. Our chapter provides a more detailed assessment of these future risks [26.6], besides assessing a richer literature on observed health impacts [26.6.1].
- *Adaptation*: AR4 found that Mexico has early warning and risk management systems, yet it faces planning and management barriers. In Canada and the US, 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]. Both chapters see ‘mainstreaming’ climate issues into decision making as key to successful adaptation [14.5; 13.5]. The current chapter provides a summary of the growing empirical literature on emerging opportunities and constraints associated with recent institutional adaptation planning activities since the AR4 [26.3.3; 26.4.3; 236.5.3; 26.6.3; 26.8.4;26.9].

In summary, scholarship on climate change impacts, adaptation and vulnerability has grown considerably since the AR4 in North America, particularly in Canada and the US. It is possible now not only to detect and attribute to anthropogenic climate change some impacts such as changes in extreme precipitation, snowmelt and snowpack, but also to examine trends showing increased insect outbreaks, wildfire events and coastal flooding. These latter trends have been shown to be sensitive to climate, but, like the local climate patterns that cause them, have not yet been positively attributed to anthropogenic climate change (see Figure 26-1).

[INSERT FIGURE 26-1 HERE
Figure 26-1 Detection and attribution of climate change impacts. Comparisons of the adequacy of currently available data to detect trends and the degree of understanding of causes of those changes in climatic extreme events in the United States (left; Peterson *et al*., 2013) and degree of understanding of the climate influence in key impacts in North America (right). Note that "climate influence" means that the impact has been documented to be sensitive to climate, not that it has been attributed to climate change. Filled boxes indicate that formal detection and attribution to climate change has been performed for the given impact; shaded boxes indicate that a trend has been detected from background variability in the given impact, but formal attribution to climate change has not occurred and the trend could be due to other drivers; and open boxes indicate that a trend has not currently been detected. Key impacts are: 1) earlier peak flow of snowmelt run-off in snow-dominated streams and rivers in western North America [26.3.1], 2) declines in the amount of water stored in spring snowpack in snow-dominated areas of western North America [26.3.1], 3) northward and upward shifts in species' distributions in multiple taxa of terrestrial species, although not all taxa and regions [26.4.1], 4) increases in coastal flooding [26.8.1], 5) increases in wildfire activity, including fire season length and area burned by wildfires in the western United States and boreal Canada [Box 26-2], 6) storm-related disaster losses in the United States (most of the increase in insurance claims paid has been attributed to increasing exposure of people and assets in areas of risk) [26.7.6.1, 26.8.1], 7) increases in bark beetle infestation levels in pine tree species in western North America [26.4.2.1], 8) yield increases due in part to increasing temperatures in Canada and higher precipitation in the US; yield variances attributed to climate variability in Ontario and Quebec; yield losses attributed to climate-related extremes across North America [26.5.1], 9) changes in storm-related mortality in the United States [26.6.1.2], 10) changes in heat-related mortality in the United States [26.6.1.2], 11) increases in tree mortality rates in old-growth forests in the western United States and western Canada from 1960-2007 [26.4.2.1], 12) changes in flooding in some urban areas due to extreme rainfall [26.3.1, 26.8.2.1], 13) increase in water supply shortages due to drought [26.8.1, 26.3], and 14) changes in cold-related heat mortality [26.6.1.2].]

26.2. Key Trends Influencing Risk, Vulnerability, and Capacities for Adaptation

26.2.1. Demographic and Socioeconomic Trends

26.2.1.1. Current Trends

Canada, Mexico and US share commonalities but also differ in key dimensions shaping risk, vulnerability and adaptation such as population dynamics, economic development, and institutional capacity. During the last years, the three countries, particularly the US, have suffered economic losses from extreme weather events (Figure 26-2). Hurricanes, droughts, floods and other climate-related hazards produce risk as they interact with increases in exposed populations, infrastructure and other assets and with the dynamics of such factors shaping vulnerability as wealth, population size and structure, and poverty (Figure 26-2 and Figure SPM.1). Population growth has been slower in Canada and US than in Mexico (Population Division, Department of Economic and Social Affairs, 2011). Yet population growth in Mexico also decreased from 3.4 percent between 1970-1980 to 1.5 percent yearly during 2000-2010. Populations in the three countries are aging at different rates (Figure 26-2). In 2010, 14.1% of the population in Canada was 60 years and older, compared to 12.7% in the US, and 6.1% in Mexico (Population Division, Department of Economic and Social Affairs, 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 US 85.8%). Urban populations are also expanding into peri-urban spaces, producing rapid changes in population and land use dynamics that can exacerbate risks from such hazards as floods and wildfires (Eakin *et al*., 2010; Romero-Lankao *et al*., 2012a). Mexico has a markedly higher poverty rate (34.8%) than Canada (9.1%) and the US (12.5%) (Figure 26-2), with weather events and climate affecting poor people's livelihood assets, including crop yields, homes, food security, and sense of place (Chapter 13, section 26.8.2). Between 1970 and 2012, a 10 percent increase in single person households – who can be vulnerable because of isolation and low income and housing quality (Roorda *et al*., 2010), has been detected in the US (Vespa *et al*., 2013).

[INSERT FIGURE 26-2 HERE
Figure 26-2: Extreme events illustrating vulnerabilities for Mexico, the United States, and Canada. This figure offers a graphic illustration of location of extreme events and relevant vulnerability trends. The observed extreme events have not been attributed to anthropogenic climate change, yet they are climate-sensitive sources of impact illustrating vulnerability of exposed systems, particularly if projected future increases in the frequency and/or intensity of such events should materialize. The figure includes:

a) A map (bottom) with population density at 1km resolution highlighting exposure and represented using 2011 Landscan data (Bright *et al*., 2012).
b) A map (top) with significant weather events taking place during 1993-2012. The map only includes disasters with overall losses of more than $1 billion US dollars in US, or more than $500 million US dollars in Mexico and Canada, adjusted to 2012 values (Source: (NatCatSERVICE, 2010). Hence, it does not include the occurrence of disasters of small and medium impact, and it does not capture the impacts of disasters on populations' livelihoods and wellbeing. Disasters represented by points that are located at the approximate geographic center of affected regions, frequently span more than one subnational jurisdiction (e.g., the 2012 drought affected 12 Mexican states, Annex Table).
c) Four panels (right) with trends in socio-demographic indicators used in the literature to measure vulnerability to hazards (Romero-Lankao *et al*., 2012): poverty rates, percentage of elderly, GDP per capita and total population (Sources: Comisión Económica para América Latina y el Caribe; U.S. Census Bureau, 2011; Statistics Canada, 2012).]

While concentrations of growing populations, water, sanitation, transportation and energy infrastructure and industrial and service sectors in urban areas can be a source of risk, geographic isolation and high dispersion of rural populations also introduce risk because of long distances to essential services (section 26.8.2). Rural populations are more vulnerable to climate events due to smaller labor markets, lower income levels and reduced access to public services. Rural poverty could also be aggravated by changes in agricultural productivity, particularly in Mexico where 65% of the rural population is poor, agricultural income is seasonal, and most households lack insurance (Scott, 2007). Food price increases, which may also result from climate events, would contribute to food insecurity (World Bank, 2011; Lobell *et al*., 2011).

Migration is a key trend affecting North America, recently with movements between urban centers and from rural Mexico into Mexico's cities, and in the US. Rates of migration from rural Mexico are positively associated with natural disaster occurrence and increased poverty trends (Saldaña-Zorilla and Sandberg, 2009), and with decreasing precipitation (Nawrotski *et al*., 2013). Studies of migration induced by past climate variability and change indicate a preference for short-range domestic movement, a complex relationship to assets with indications that the poorest are less able to migrate, and the role of pre-existing immigrant networks in facilitating international migration (Oppenheimer, 2013).

North America has become more economically integrated following the 1994 North American Free Trade Agreement. Prior to a 2007-2008 reduction in trade, the three countries registered dynamic growth in industry, employment and global trade of agricultural and manufactured goods (World Bank, 2009). Notwithstanding North America's economic dynamism, increased socioeconomic disparities (Autor *et al*., 2008) have affected such determinants of vulnerability as differentiated human development and institutional capacity within and across countries.

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

Extending over 3111 km (1933 miles; (U.S. Census Bureau, 2011), the border between the United States and Mexico, which can be defined in different ways (Varady and Ward, 2009), illustrates the challenges and opportunities of responding to climate change in a transboundary context. Changing regional climate conditions and socioeconomic processes combined shape differentiated vulnerabilities of exposed populations, infrastructure and economic activities.

Since at least 1999, the region has experienced high temperatures and aridity anomalies leading to drought conditions (Woodhouse *et al*., 2010; Wilder *et al*., 2013) affecting large areas on both sides of the border, and considered the most extreme in over a century of recorded precipitation patterns for the area (Seager and Vecchi, 2010; Cayan *et al*., 2010; Nielsen-Gammon, 2011). Streamflow in already oversubscribed rivers such as the Colorado and Rio Grande (Nakaegawa *et al*., 2013) has decreased. Climatological conditions for the area have been unprecedented, with sustained high temperatures that may have exceeded 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).

The population of the Mexico-US Border is rapidly growing and urbanizing, doubling from just under 7 million in 1983 to over 15 million in 2012 (Peach and Williams, 2007). Since 1994, rapid growth in the area has been fueled by rapid economic development subsequent to passage of the North American Free Trade Agreement (NAFTA). Between 1990 and 2001 the number of *assembly factories* or *maquiladoras* in Mexico grew 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 more than 3,000 *maquiladoras* located along the border (U.S. Environmental Protection Agency and Secretaría de Medio Ambiente y Recursos Naturales, 2011; U.S. Environmental Protection Agency, 2012).

Notwithstanding this growth, 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, particularly in Mexico, 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 capacity to respond to climate needs to take existing gaps into account. Additionally, there is a prevalence of incipient or actual conflict (Mumme, 1999), given by currently or historically contested allocation of land and water resources (e.g., an over-allocated Colorado river ending in Mexico above the Sea de Cortes (Getches, 2003). Climate change, therefore, would bring additional significant consequences for the region’s water resources, ecosystems, and rural and urban settlements.

The impacts of regional climatic and non-climatic stresses compound existing urban vulnerabilities that are different across countries. For instance, besides degrading highly diverse ecosystems (Wilder *et al*., 2013), residential growth in flood-prone areas in Ciudad Juarez has not been complemented with the provision of determinants of adaptive capacity to residents, such as housing, health care and drainage infrastructure. As a result, while differences in mean hazard scores are not significantly different between Ciudad Juarez (Mexico) and El Paso (US), social vulnerability and average risk are three times and two times higher in Ciudad Juárez than in El Paso respectively (Collins, 2008).

Projected warming and drying would impose additional burdens on already stressed water resources and ecosystems and compound existing vulnerabilities for populations, infrastructure and economic activities (Wilder *et al*., 2013). The recent drought in the region illustrated the multiple dimensions of climate-related events, including notable negative impacts on the agricultural sector, water supplies, food security, and risk of wildfire (discussed in Box 26.2) (Wehner *et al*., 2011; Schwalm *et al*., 2012; Hoerling *et al*., 2012).

Adaptation opportunities and constraints 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 issues, such as the US-Mexico International Boundary and Water Commission agreement (International Boundary and Water Commission, 2012), constraints to effective cooperation and collaboration include different governance structures (centralized in Mexico, decentralized in the US); institutional fragmentation; asymmetries in the use and dissemination of information, and language (Wilder *et al*., 2010; Megdal and Scott, 2011; Wilder *et al*., 2013).

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26.2.1.2. Future Trends

The North American population is projected to continue growing, reaching between 531.8 (B2) and 660.1 (A2) million by 2050 (International Institute for Applied System Analysis, 2007). The percentage of elderly people (over

64 years) is also projected to continue to increase, by 23.4%-26.9% in Canada, 12.4%-18.4 % in Mexico, and 17.3%-20.9% in the US by 2050 (B2 and A2 respectively) (International Institute for Applied System Analysis, 2007). The elderly are highly vulnerable to extreme weather events (heat waves in particular, Figure 26-2) (Martiello and Giacchi, 2010; Diffenbaugh and Scherer, 2011; Romero-Lankao, 2012; White-Newsome *et al.*, 2012). Numbers of single-person households and female-headed households — both of which are vulnerable because of low income and housing quality – are anticipated to increase (Roorda *et al.*, 2010). Institutional capacity to address the demands posed by increasing numbers of vulnerable populations may also be limited, with resulting stress on health and the economy.

Three other shifts are projected to influence impacts, vulnerabilities and adaptation to climate change in North America: urbanization, migration, and socioeconomic disparity. With small differences between countries, both the concentration of growing populations in some urban areas and the dispersion of rural populations are projected to continue to define North America by 2050. Assuming no change in climate, 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 (Chapter 13), is expected to expand to low-income households, minorities, and women, which could increase the coping capacity of households and have a positive impact on economic growth (Goujon *et al.*, 2004). However, the continuation of current patterns of economic disparity and poverty would hinder future adaptive capacity. Inequality in Mexico is larger (Figure 26-2), having a Gini coefficient (according to which the higher the number the higher economic disparity) of 0.56, in contrast to 0.317 for Canada and 0.389 for the US (Organisation for Economic Co-operation and Development, 2010). Mexico is one of five 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).

Some studies project increased North American migration in response to climate change. Feng, Krueger and Oppenheimer (2010) estimated the emigration of an additional 1.4 to 6.7 million Mexicans by 2080 based on projected maize yield declines, range depending on model (B1, UKMO and GDFL). Oppenheimer speculates that the indirect impacts of migration “could be as substantial as the direct effects of climate change in the receiving area,” because the arrival migrants can increase pressure on climate sensitive urban regions (Oppenheimer, 2013, 442).

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 4 (*Observations: Cryosphere*), WGI Chapter 12 (*Long-term Climate Change: Projections, Commitments and Irreversibility*), 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

It is *very likely* that mean annual temperature has increased over the past century over most of North America (WGI SPM.1) (Figure 26-3). Observations also show increases in the occurrence of severe hot events over the US over the late 20th century (Kunkel *et al.*, 2008), a result in agreement with observed late-20th-century increases in extremely hot seasons over a region encompassing northern Mexico, the US 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.*, 2010) WGI 2.6.1, decreases in cold spells over the US (Kunkel *et al.*, 2008) WGI 2.6.1, and increasing ratio of record high to low daily temperatures over the US (Meehl *et al.*, 2009). However, warming has been less pronounced and less robust over areas of the central and southeastern US (e.g., (Alexander et al., 2006; Peterson *et al.*, 2008); WGI 2.6.1; WGI SPM.1) (Figure 26-3). It is possible that this pattern of muted temperature change 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., (Meehl *et al*., 2012; Kumar *et al*., 2013b).

[INSERT FIGURE 26-3 HERE
Figure 26-3: Observed and projected Changes in annual temperature and precipitation. (Top panel, left) observed temperature trends from 1901-2012 determined by linear regression [WGI AR5 Figures SPM.1 and 2.21]. (Bottom panel, left) Observed precipitation change from 1951-2010 determined by linear regression. [WGI AR5 Figure SPM.2] For observed temperature and precipitation, trends have been calculated where sufficient data permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level. Diagonal lines indicate areas where change is not significant (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent change in annual mean precipitation for 2046-2065 and 2081-2100 under RCP2.6 and 8.5. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability, and >90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, less than the baseline variability in >66% of models. (There may be significant change at shorter timescales such as seasons, months, or days.). Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See also Annex I of WGI AR5. [Boxes 21-3 and CC-RC]]

It is *very likely* that annual precipitation has increased over the past century over areas of the eastern US and Pacific Northwest (WGI Fig. 2.29) (Figure 26-3). Observations also show increases in heavy precipitation over Mexico, the US and Canada between the mid-20th century and the early 21st century (Peterson and Baringer, 2009; DeGaetano, 2009; Pryor *et al*., 2009); WGI 2.6.2. Observational analyses of changes in drought are more equivocal over North America, with mixed sign of trend in dryness over Mexico, the US and Canada (WGI 2.6.2 and Fig 2.42) (Dai, 2011; Sheffield *et al*., 2012). There is also 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 US 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 4.5 and Fig. 4.21). Observations also show decreasing mass and length of glaciers in North America (WGI 4.3 and Fig. 4.9, 4.10, 4.11). Further, in assessing changes in the hydrology of the western US, it has been concluded that "up to 60% of the climate-related trends of river flow, winter air temperature, and snow pack between 1950 and 1999 are human-induced"(Barnett *et al*., 2008).

Observational limitations prohibit conclusions about trends in severe thunderstorms (WGI 2.6.2) and tropical cyclones (WGI 2.6.3) over North America. 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 "Global mean sea level (GMSL) has risen by 0.19 [0.17–0.21] m over the period 1901–2010" and that "it is *very likely* that the mean rate was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010 and increased to 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010" (WGI 3 Executive Summary). In addition, observed changes in extreme sea level have been caused primarily by increases in mean sea level (WGI 3.7.5). 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 US) or vertical land motion (such as high rates along the US Gulf Coast), but the persistence of the observed regional patterns is unknown (WGI 3.7.3).

26.2.2.2. Climate Change Projections

Chapters 11 and 12 of the WGI contribution to the AR5 assess near-term and long-term future climate change, respectively. Chapter 14 of the WGI contribution assesses processes that are important for regional climate change, with section 14.8.3 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* increases in mean annual temperature over North America, with *very likely* increases in temperature over all land areas in the mid- and late-21st-century periods in RCP2.6 and RCP8.5 (Figure 26-3). Ensemble-mean changes in mean annual temperature exceed 2˚C over most land areas of all three countries in the mid-21st-century period in RCP8.5 and the late-21st-century period in RCP8.5, and exceed 4˚C over most land areas of all three countries in the late-21st-century period in RCP8.5. However, ensemble-mean changes in mean annual temperature remain within 2˚C above the late 20th century baseline over most North American land areas in both the mid- and late-21st-century periods in RCP2.6. The largest changes in mean annual temperature occur over the high latitudes of the United States and Canada, as well as much of eastern Canada, including greater than 6˚C in the late-21st-century period in RCP8.5. The smallest changes in mean annual temperature occur over areas of southern Mexico, the Pacific Coast of the United States, and the southeastern United States.

The CMIP5 ensemble projects warming in all seasons over North America beginning as early as the 2016-2035 period in RCP2.6, with the greatest warming occurring in winter over the high latitudes (WGI Annex I and Figure 26-3)(Diffenbaugh and Giorgi, 2012). The CMIP5 and CMIP3 ensembles suggest that the response of warm-season temperatures to elevated radiative forcing is larger as a fraction of the baseline variability than the response of cold-season temperatures (Diffenbaugh and Scherer, 2011; Kumar *et al*., 2013b), and the CMIP3 ensemble suggests that the response of temperature in low-latitude areas of North America is larger as a fraction of the baseline variability 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 US, northern Mexico and the northeastern US than over the central and southeastern US (Diffenbaugh *et al*., 2011), a result that is similar to the observed pattern of temperature trend significance in the US (Figure 26-3).

Most land areas north of 45˚N exhibit *likely* or *very likely* increases in mean annual precipitation in the late-21st-century period in RCP8.5 (Figure 26-3). The high latitude areas of North America exhibit *very likely* changes in mean annual precipitation throughout the illustrative RCP periods, with *very likely* increases occurring in the mid-21st-century period in RCP2.6 and becoming generally more widespread at higher levels of forcing. In contrast, much of Mexico exhibits *likely* decreases in mean annual precipitation beginning in the mid-21st-century period in RCP8.5, with the area of *likely* decreases expanding to cover most of Mexico and parts of the southcentral and southwestern US in the late-21st-century period in RCP8.5. *Likely* changes in mean annual precipitation are much less common at lower levels of forcing. For example, *likely* changes in mean annual precipitation in the mid- and late-21st-century periods in RCP2.6 are primarily confined to increases over areas of Canada and Alaska, with no areas of Mexico and very few areas of the contiguous US exhibiting differences that exceed the baseline variability in more than 66% of the models.

CMIP5 projects increases in winter precipitation over Canada and Alaska, consistent with projections of a poleward shift in the dominant cold-season stormtracks (WGI 14.8.3) (Yin, 2005), extratropical cyclones (Trapp *et al*., 2009) and areas of moisture convergence (WG1 14.8.3), as well as with projections of a shift towards positive North Atlantic Oscillation (NAO) trends (Hori *et al*., 2007) WGI 14.8.3). CMIP5 also projects decreases in winter precipitation over the southwestern US and much of Mexico associated with the poleward shift in the dominant stormtracks and the expansion of subtropical arid regions (Seager and Vecchi, 2010); WGI 14.8.3). 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) (Cayan *et al*., 1999; Findell and Delworth, 2010; Seager and Vecchi, 2010); WGI 14.8.3), and not all CMIP5 models simulate the observed recent hydrologic trends in the region (Kumar *et al*., 2013a)

For seasonal-scale extremes, CMIP5 projects substantial increases in the occurrence of extremely hot seasons over North America in early, middle and late 21st century periods in RCP8.5 (Diffenbaugh and Giorgi, 2012) (Figure 26-4). For example, during the 2046-2065 period in RCP8.5, more than 50% of summers exceed the respective late-20th-century maximum seasonal temperature value over most of the continent. CMIP3 projects similar increases in extremely hot seasons, including greater than 50% of summers exceeding a mid-20th-century baseline throughout much of North America by the mid-21st-century in the A2 scenario (Duffy and Tebaldi, 2012), and greater than 70% of summers exceeding the highest summer temperature observed on record over much of the western US, southeastern US and southern Mexico by the mid-21st-century in the A2 scenario (Battisti and Naylor, 2009). CMIP5 also projects substantial decreases in snow accumulation over the US and Canada (Diffenbaugh *et al*., 2012) (Figure 26-4), suggesting that the increases in cold-season precipitation over these regions reflect a shift towards increasing fraction of precipitation falling as rain rather than snow (Diffenbaugh *et al*., 2012). Over much of the western US and western Canada, greater than 80% of years exhibit March snow amount that that is less than the late-20th-century median value beginning in the mid-21st-century period in RCP8.5, with the ensemble-mean change exceeding 2 standard deviations of the ensemble spread. Likewise, greater than 60% of years exhibit March snow amount that is less than the late-20th-century minimum value in the late-21st-century period in RCP8.5, with the ensemble-mean change exceeding 2 standard deviations of the ensemble spread (Diffenbaugh and Giorgi, 2012) (Figure 26-4). CMIP5 also projects increases in the occurrence of extremely dry summer seasons over much of Mexico, the US and southern Canada (Figure 26-4). The largest increases occur over southern Mexico, where greater than 30% of summers in the late-21st-century period in RCP8.5 exhibit seasonal precipitation that is less than the late 20th century minimum summer precipitation.

[INSERT FIGURE 26-4 HERE
Figure 26-4: Projected changes in extremes in North America. (a) The percentage of years in the 2046–2065 period of RCP8.5 in which the summer temperature is greater than the respective maximum summer temperature of the 1986–2005 baseline period (Diffenbaugh and Giorgi, 2012). (b) The percentage of years in the 2080-2099 period of RCP8.5 in which the summer precipitation is less than the respective minimum summer precipitation of the 1986-2005 baseline period (Diffenbaugh and Giorgi, 2012) (c) The percentage difference in the 20-year return value of annual precipitation extremes between the 2046-2065 period of RCP4.5 and the 1986-2005 baseline period (from (Kharin *et al*., 2013). The hatching indicates areas where the differences are not significant at the 5% level. (d) The percentage of years in the 2070-2099 period of RCP8.5 in which the March snow water equivalent is less than the respective minimum March snow water equivalent of the 1976–2005 period (Diffenbaugh *et al*., 2012). The black (white) stippling indicate areas where the multimodel mean exceeds 1.0 (2.0) standard deviations of the multi-model spread. (a-d) The RCPs and time periods are those used in the peer-reviewed studies in which the panels appear. The 2046-2065 period of RCP8.5 and the 2046-2065 period of RCP4.5 exhibit global warming in the range of 2-3˚C above the pre-industrial baseline (WGI Fig. 12.40). The 2080-2099 and 2070-2099 periods of RCP8.5 exhibit global warming in the range of 4-5˚C above the pre-industrial baseline (WGI Fig. 12.40).]

For daily-scale extremes, almost all areas of North America exhibit *very likely* increases of at least 5˚C in the warmest daily maximum temperature by the late-21st-century period in RCP8.5. Likewise, most areas of Canada exhibit *very likely* increases of at least 10˚C in the coldest daily minimum temperature by the late-21st-century period in RCP8.5, while most areas of the US exhibit *very likely* increases of at least 5˚C and most areas of Mexico exhibit *very likely* increases of at least 3˚C (Sillmann *et al*., 2013) (WGI Fig. 12.13). In addition, almost all areas of North America exhibit *very likely* increases of 5% to 20% in the 20-year return value of extreme precipitation by the mid-21st-century period in RCP4.5 (Figure 26-4), while most areas of the US and Canada exhibit *very likely* increases of at least 5% in the maximum 5-day precipitation by the late-21st-century period in RCP8.5 (Sillmann *et al*., 2013)(WGI Fig. 12.13). Further, almost all areas of Mexico exhibit *very likely* increases in the annual maximum number of consecutive dry days by the late-21st-century period in RCP8.5 (Sillmann *et al*., 2013) (WGI Fig. 12.13).

26.3. Water Resources and Management

Water withdrawals are exceeding stressful levels 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 (Romero-Lankao, 2010; National Water Commission of Mexico, 2010; Sosa-Rodriguez, 2010; Averyt *et al*., 2011;

Environment Canada, 2013a). Water quality is also a concern with 10% to 30% of the surface monitoring sites in Mexico having polluted water (National Water Commission of Mexico, 2010), and about 44% of assessed stream miles, and 64% of assessed lake areas in the US not clean enough to support their uses (U.S. Environmental Protection Agency, 2004). Stations in Canada's 16 most populated drainage basins reported at least fair quality, with many reporting good or excellent quality (Environment Canada, 2013b). In basins outside of the populated areas there are some cases of declining water quality where impacts are related to resource extraction, agriculture, and forestry (Hebben, 2009).

Water management infrastructure in most areas of North America is in need of repair, replacement or expansion (Section 26.7). Climate change, land use changes and population growth, and demand increases will add to these stresses(U.S. Global Change Research Program, 2009).

26.3.1. Observed Impacts of Climate Change on Water Resources

Droughts and Floods: As reported in WG1, Chapter 10 and 26.2.2.1, it is not possible to attribute changes in drought frequency in North America to anthropogenic climate change (Prieto-González *et al.*, 2011; Axelson *et al.*, 2012; Orlowsky and Senevirantne, 2013) (Figure 26-1). Few discernible trends in flooding have been observed in the US (Chapter 3). Changes in the magnitude or frequency of flood events have not been attributed to climate change. Floods are generated by multiple mechanisms (e.g., land use, seasonal changes and urbanization); trend detection is confounded by flow regulation, teleconnections and long-term persistence (section 26.2.2.1; (Kumar *et al.*, 2009; Collins, 2009; Smith *et al.*, 2010; Villarini and Smith, 2010; Villarini *et al.*, 2011; Hirsch and Ryberg, 2012; Prokoph *et al.*, 2012; Instituto Nacional de Ecología y Cambio Climático, 2012a; Peterson *et al.*, 2013).

*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) . Chapter 3, WG2 notes the correlation between changes in streamflow and observed regional changes in temperature and precipitation. Kumar et al. (2009) suggest that human activities that have influenced observed trends in streamflow making attribution of changes to climate difficult in many watersheds. Nonetheless, earlier peak flow of snowmelt run-off in snow-dominated streams and rivers in western North America has been formally detected and attributed to anthropogenic climate change (Barnett *et al.*, 2008; Das *et al.*, 2011) (Figure 26-1).

Snow Melt: Warm winters produced earlier runoff and discharge but less snow water equivalent and shortened snowmelt seasons in many snow-dominated areas of North America (Barnett *et al.*, 2005; Rood *et al.*, 2008; Reba *et al.*, 2011) (Section 26.2.2., Chapter 3).

26.3.2. Projected Climate Change Impacts and Risks

26.3.2.1. Water Supply

Most of this assessment focuses on surface water as there are few groundwater studies (Tremblay *et al.*, 2011; Georgakakos *et al.*, 2013). Impacts and risks vary by region and model used.

In arid and semi-arid western US and Canada and in most of Mexico, except the southern tropical area, water supplies are projected to be further stressed by climate change, resulting in less water availability and increased drought conditions (Seager *et al.*, 2007; Instituto Mexicano de Tecnología del Agua, 2010; Cayan *et al.*, 2010; Montero Martinez *et al.*, 2010; MacDonald, 2010; Comisión Nacional del Agua, 2011; Prieto-González *et al.*, 2011; Bonsal *et al.*, 2012; Sosa-Rodriguez, 2013; Orlowsky and Senevirantne, 2013; Diffenbaugh and Field, 2013). Compounding factors include salt water intrusion, and increased groundwater and surface water pollution (Leal Asencio *et al.*, 2008).

In the US southwest and southeast, ecosystems and irrigation are projected to be particularly stressed by decreases in water availability due to the combination of climate change, growing water demand, and water transfers to urban and industrial users (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 (Dwyer *et al*., 2012). In the Rio Grande basin, New Mexico, runoff is projected decrease by 8%-30% by 2080 due to climate change. Water transfers may entail significant transaction costs associated with adjudication and potential litigation; and might have economic, environmental, social, and cultural impacts that vary by water user (Hurd and Coonrod, 2012). In Mexico, water shortages combined with increased water demands are projected to increase surface and groundwater over exploitation (Comisión Nacional del Agua, 2011).

Other parts of North American are projected to have different climate risks. The vulnerability of water resources over the tropical southern region of Mexico is projected to be low for 2050: precipitation decreases from 10%-5% in the summer and no precipitation changes in the winter. After 2050, greater winter precipitation is projected, increasing the possibility of damaging hydropower and water storage damns by floods, while precipitation is projected to decrease by 40%-35% in the summer (Instituto Mexicano de Tecnología del Agua, 2010).

Throughout the 21st century, cities in NW Washington are projected to have drawdown of average seasonal reservoir storage in the absence of demand reduction because of less snow pack even though annual stream flows increase. Without accounting for demanding increases, projected reliability of all systems remains above 98% through mid and late century (Vano *et al*., 2010a; Comisión Nacional del Agua, 2011). Throughout the eastern US, water supply systems will be negatively impacted by lost snowpack storage; rising sea levels contributing to increased storm intensities and salt water intrusion; possibly lower stream-flows; land use and population changes; and other stresses (Sun *et al*., 2008; Obeysekera *et al*., 2011).

In Canada’s Pacific Northwest Region, cool season flows are expected to increase, while warm seasons flows would decrease (Hamlet, 2011). Southern Alberta, where approximately two-thirds of Canadian irrigated land is located, is projected to experience declines in mean annual stream flow, especially during the summer (Shepherd *et al*., 2010; Poirier and de Loë, 2012; Tanzeeba and Gan, 2012). In the Athabasca River Basin in northern Alberta, modeling results consistently indicate large projected declines in mean annual flows (Kerkhoven and Gan, 2011). In contrast, modeling results for basins in Manitoba indicate an increase in mean annual runoff (Choi *et al*., 2009). Some model results for the Fraser River Basin in British Columbia indicate increases in mean annual runoff by the end of the 21st Century, while others indicate decreases (Kerkhoven and Gan, 2011). In central Quebec, (Chen *et al*., 2011b) project a general increase in discharge during November-April, and a general decrease in summer discharge under most climate change conditions.

26.3.2.2. Water Quality

Many recent studies project water quality declines due to the combined impacts of climate change and development (Daley *et al*., 2009; Tu, 2009; Praskievicz and Chang, 2011; Wilson and Weng, 2011; Tong *et al*., 2012). 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*., 2011; 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; Taner *et al*., 2011; Praskievicz and Chang, 2011).

Changes in physical-chemical-biological parameters and micropollutants are predicted to negatively affect drinking water treatment and distribution systems (Delpla *et al*., 2009; Carriere *et al*., 2010; Emelko *et al*., 2011). Wastewater treatment plants would be more vulnerable as increases in rainfall and wet weather lead to higher rates of inflow and infiltration (New York City Department of Environmental Protection, 2008; King County Department of Natural Resources and Parks, 2008; Flood and Cahoon, 2011). They would 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 sewage collection systems (Rosenzweig *et al*., 2007; King County Department of Natural Resources and Parks, 2008)

26.3.2.3. 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 (Committee on Flood Control Alternatives in the American River Basin *et al*., 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 infrastructure that takes climate change into account (Hejazi and Markus, 2009; Mailhot and Duchesne, 2010; Sosa-Rodriguez, 2010). (Ntelekos *et al*., 2010) estimate that annual riverine flood losses in the USA could increase from approximately $2 billion now to $7-$19 billion annually by 2100 depending upon emission scenario and economic growth rate.

26.3.2.4 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 (Comisión Intersecretarial de Cambio Climatico, 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 under several emission scenarios. it is projected to increase in 2040 by approximately 5% in the winter and decrease by approximately 13% in the summer, with annual reductions of approximately 2.5%. Larger increases and decreases are projected by 2080 (Hamlet *et al*., 2010). On the Peribonka River system in Quebec, annual mean hydropower production will similarly decrease in the short-term increase by as much as 18 % in late 21st century (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 low river levels during droughts (Georgakakos *et al*., 2013).

26.3.3. Adaptation

There are a range of structural and non-structural adaptation measures being implemented with many being 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 (Comisión Intersecretarial de Cambio Climatico, 2009; National Water Commission of Mexico, 2010; Sosa-Rodriguez, 2010; Romero-Lankao, 2010). Regina, SK has increased urban water conservation efforts (Natural Resources Canada, 2008).

The 540-foot high, 1300-foot long concrete Ross Dam in the state of Washington, US was built on a special foundation so it could later be raised in height (Simmons, 1974). 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 consumption by different users such as Mexican and Canadian farmers and in households of several Canadian cities (Instituto Nacional de Ecología y Cambio Climático, 2006; Natural Resources Canada, 2008). Agreements and regulations are underway such as the 2009 SECURE Water Act which establishes a federal climate change adaptation program with required studies to assess future water supply risks in the western U.S (42 USC § 10363). One such large, multi-year study was recently completed in the US for the Colorado River (Bureau of Reclamation, 2013) and others are planned. Agreements and regulations are underway, such as the 2007 Shortage Sharing Agreement for the management of the Colorado River, driven by concerns about water conservation, planning, better reservoir coordination, and preserving flexibility to respond to climate change(Bureau of Reclamation, 2007). Quebec Province is requiring dam safety inspections every 10 years to account for new knowledge on climate change impacts (Centre d'expertise hydrique du Québec, 2003). Expanded beyond flood and hydropower management to now include climate change, the Columbia River Treaty is a good example of an international treaty to manage a range of water resources challenges(U.S. Army Corps of Engineers and Bonneville Power Administration, 2013).

26.4. Ecosystems and Biodiversity

26.4.1. Overview

Recent research has documented gradual changes in physiology, phenology and distributions in North American ecosystems consistent with warming trends (Dumais and Prévost, 2007). Changes in phenology and species' distributions, particularly in the United States and Canada, have been attributed to rising temperatures, which have in turn been attributed to anthropogenic climate change via joint attribution (Root *et al*., 2005; Vose *et al*., 2012). Concomitant with 20th century temperature increases, northward and upward 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 distribution shifts consistent with climate-change interact with other environmental changes such as land-use change, hindering the ability of species to respond (Ponce-Reyes *et al*., 2013).

A range of techniques have been applied to assess the vulnerability of North American ecosystems and species to changes in climate (Loarie *et al*., 2009; Anderson *et al*., 2009; Glick and Stein, 2011). 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). Since the AR4, the role of extreme events, including droughts, flood, hurricanes, storm surges, and heat waves, is a more prominent theme in studies of climate change impacts on North American ecosystems (Chambers *et al*., 2007; IPCC, 2012).

A number of ecosystems in North America are vulnerable to climate change. For example, species in alpine ecosystems are at high risk due to limited geographic space into which to expand (Villers-Ruiz and Castañeda-Aguado, In press). Many forest ecosystems are susceptible to wildfire and large-scale mortality and infestations events (section 26.4.1). Across the continent, potentially rapid rates of climate change may require location shifts at velocities well outside the range in historical reconstructions (Sandel *et al*., 2011; Schloss *et al*., 2012). Changes in temperature, precipitation amount, and carbon dioxide concentrations can have different effects across species and ecological communities (Parmesan, 2006; Matthews *et al*., 2011), leading to ecosystem disruption and reorganization (Smith *et al*., 2011; Dukes *et al*., 2011), as well as movement or loss.

The following section focuses in more depth on climate vulnerabilities in forests and coastal ecosystems. These ecosystems span all three North American countries, are illustrative cases of where understanding the opportunities for conservation and adaptation practices is important, and recent research advances and new evidence of increased vulnerabilities since AR4 motivate further exploration. Further treatment of grasslands and shrublands can be found in AR5 WGII 4.3.3.2.2, wetlands and peatlands 4.3.3.3, and tundra, alpine, and permafrost systems in 4.3.3.4. Additional synthesis of climate change impacts on terrestrial, coastal and ocean ecosystems can be found in Chapter 8 of the US National Climate Assessment (Groffman *et al*., 2013).

26.4.2. Tree Mortality and Forest Infestation

26.4.2.1. 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 drought exacerbated by high summertime temperatures in trembling aspen (*Populus tremuloides*), pinyon pine (*Pinus edulis*) and lodgepole pine (*Pinus contorta*) since the early 2000s (Breshears *et al*., 2005; Hogg *et al*., 2008; Raffa *et al*., 2008; Michaelian *et al*., 2011; Anderegg *et al*., 2012). In 2011 and 2012 forest dieback in Northern and central Mexico was associated with extreme temperatures and severe droughts (Comisión Nacional Forestal, 2012a).Widespread forest-mortality events triggered by extreme climate events can alter ecosystem structure and function (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*., 2009). Average annual mortality rates increased from less than 0.5% of trees per year in the 1960s in forests of western Canada and the US to, respectively, 1.5-2.5% (Peng *et al*., 2011), and 1.0-1.5% in the 2000s in the US (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 have the potential to turn forests into carbon sources (Kurz *et al*., 2008a; Kurz *et al*., 2008b; Hicke *et al*., 2012). Warm winters in western Canada and US have increased winter survival of the larvae of bark beetles, helping drive large-scale forest infestations and forest die-off in western North America since the early 2000s (Bentz *et al*., 2010). Beginning in 1994, mountain pine beetle outbreaks have severely affected over 18 million hectares of pine forests in British Columbia, and outbreaks are expanding northwards (Energy, Mines and Resources: Forest Management Branch, 2012).

26.4.2.2. Projected Impacts and Risks

Projected increases in drought severity in southwestern forests and woodlands in United States and northwestern Mexico suggest that these ecosystems may be increasingly vulnerable, with impacts including vegetation mortality (Seager and Vecchi, 2010; Williams *et al*., 2010; Overpeck and Udall, 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 from tree rings indicates that projected drought stress by the 2050s in the SRES A2 scenario from the CMIP3 model ensemble, due primarily to warming-induced rises in vapor pressure deficit, exceeds the most severe droughts of the past 1,000 years (Park *et al*., 2013).

Under a scenario with large changes in global temperature (SRES A2) increases in growing-season temperature in forest soils in southern Quebec are as high as 5.0 C towards the end of the century and decreases of soil water content reach 20-40% 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 shifts of insect and pathogen distributions into higher latitudes and elevations (Bentz *et al*., 2010). Predicted climate warming is expected to have effects on bark beetle population dynamics in the western United States, western Canada, and northern 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 bark beetles on forest resources are expected to increase (Waring *et al*., 2009).

Wildfire, a potentially powerful influence on North American forests in the 21st century, is discussed in Box 26-2.

26.4.3. Coastal Ecosystems

Highly productive estuaries, coastal marshes and mangrove ecosystems are present along the Gulf coast and the East and West coasts of North America. These ecosystems are subject to a wide range of non-climate stressors, including urban and tourist developments and the indirect effects of overfishing (Mortsch *et al*., 2006; Bhatti *et al*., 2006; Lund *et al*., 2007; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad *et al*., 2007). Climate change adds risks from sea-level rise, warming, ocean acidification, extratropical cyclones, altered upwelling, and hurricanes and other storms.

26.4.3.1. Observed Climate Impacts and Vulnerabilities

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 and wetlands, oyster beds, seagrass and mangroves (Feagin *et al*., 2005; Cooper *et al*., 2008; Najjar *et al*., 2010; Ruggiero *et al*., 2010; McKee, 2011; Martinez Arroyo *et al*., 2011).

Increases in sea surface temperature in estuaries alter metabolism, threatening species, especially cold water fish (Crawford *et al*., 2007). Historical warm periods have coincided with low salmon abundance and restriction of fisheries in Alaska (Crozier *et al*., 2008; U.S. Global Change Research Program, 2009). North Atlantic cetaceans, and tropical coral reefs in the Gulf of California and the Caribbean have been affected by increases in the incidence of diseases associated with warm waters and low water quality (Mumby *et al*., 2011; International Council for the Exploration of the Sea, 2011).

Increased concentrations of CO_2 in the atmosphere due to human emissions are causing ocean acidification (Executive summary chapters 5 and 6; FAQ 5.1). Along the temperate coasts of North America acidification directly affects calcareous organisms, including colonial mussel beds, with indirect influences on food webs of benthic species (Wootton *et al*., 2008). Increased acidity in conjunction with high temperatures has been identified as a serious threat to coral reefs and other marine ecosystems in the Bahamas and the Gulf of California(Doney *et al*., 2009; Hernández *et al*., 2010; Mumby *et al*., 2011).

Tropical storms and hurricanes can have a wide range of effects on coastal ecosystems, potentially altering hydrology, geomorphology (erosion), biotic structure in reefs and nutrient cycling. Hurricane impacts on the coastline change dramatically the marine habitat of sea turtles, reducing feeding habitats, such as coral reefs and areas of seaweed, and nesting places. (Márquez, R. and Jiménez, Ma. del C., 2010; Liceaga-Correa *et al*., 2011)

26.4.3.2. 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*., 2011), will threaten many plants in coastal ecosystems through increased inundation, erosion, and salinity levels. In settings where landward shifts are not possible, a 1 m rise in sea level will result in loss of wetlands and mangroves along the Gulf of Mexico of 20% (in Tamaulipas) to 94% (in Veracruz) (Flores Verdugo *et al*., 2010).

Projected impacts of increased water temperatures include contraction of coldwater fish habitat and expansion of warm-water fish habitat (Mantua *et al*., 2010), which can increase the presence of invasive species that threaten resident populations (Janetos *et al*., 2008). Depending on scenario, Chinook salmon in the Pacific Northwest may decline by 20 to 50% by 2040-50 (Battin *et al*., 2007; Crozier *et al*., 2008), integrating across restrictions in productivity and abundance at the southern end of their range and expansions at the northern end (Azumaya *et al*., 2007), although habitat restoration and protection particularly at lower elevations may help mitigate declines in abundance.

Continuing ocean acidification will decrease coral growth and interactions with temperature increases will lead to increased risk of coral bleaching, leading to declines in coral ecosystem biodiversity (Veron *et al*., 2009) (5.4.2.4, Box CC-OA). Oyster larvae in Chesapeake Bay grew more slowly when reared with CO_2 levels between 560 and 480ppm compared to current environmental conditions (Gazeau *et al*., 2007; Miller *et al*., 2009; Najjar *et al*., 2010).

While future trends in thunderstorms and tropical cyclones are uncertain (26.2.2), any changes, particularly an increase in the frequency of category 4 and 5 storms (Bender *et al*., 2010; Knutson *et al*., 2010) could have profound impacts on mangrove ecosystems, which require 25 years for recovery from storm damage (Kovacs *et al*., 2004; Flores Verdugo *et al*., 2010).

26.4.4. Ecosystems Adaptation, and Mitigation

In North America, a number of adaptation strategies, are being applied in novel and flexible ways to address the impacts of climate change (Mawdsley *et al*., 2009; National Oceanic and Atmospheric Administration, 2010; Gleeson *et al*., 2011; Poiani *et al*., 2011). The best of these are based on detailed knowledge of the vulnerabilities and sensitivities of species and ecosystems, and with a focus on opportunities for building resilience through effective ecosystem management. Government agencies and nonprofit organizations have established initiatives that emphasize the value of collaborative dialogue between scientists and practitioners, indigenous communities, and grass-roots organizations to develop no-regrets and co-benefits adaptation strategies (Ogden and Innes, 2009; Gleeson *et al*., 2011; Halofsky *et al*., 2011; Cross *et al*., 2012; Instituto Nacional de Ecología y Cambio Climático, 2012b; Cross *et al*., 2013).

Examples of adaptation measures implemented to respond to climate change impacts on ecosystems are diverse. They include programs to reduce the incidence of Canadian forest pest infestations (Johnston *et al*., 2010); breeding programs for resistance to diseases and insect pests (Yanchuk and Allard, 2009); use of forest programs to reduce the incidence of forest fires and encourage agroforestry in areas of Mexico (Sosa-Rodriguez, 2013); and selection by forest or fisheries managers of activities that are more adapted to new climatic conditions (Vasseur and Catto, 2008). Example programs have addressed commercial fishing, mass tourism (Pratchett *et al*., 2008), and enforcement mechanisms for using water regulation technologies to maintain quantity and quality in wetlands around the Great Lakes and San Francisco, California (Mortsch *et al*., 2006; Okey *et al*., 2012). Assisted migration is increasingly discussed as a potential management option to maintain health and productivity of forests; yet the technique has logistical and feasibility challenges (Keel, 2007; Hoegh-Guldberg *et al*., 2008; Winder *et al*., 2011).

Several lines of evidence indicate that effective adaptation requires changes in approach and becomes much more difficult if warming exceeds 2°C above preindustrial levels (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad *et al*., 2007; Mansourian *et al*., 2009; U.S. Forest Service, 2010; Glick and Stein, 2011; Barragan *et al*., 2011; Instituto Nacional de Ecología y Cambio Climático, 2012b). Even though options for effective adaptation are increasingly constrained at warming over 2°C, some opportunities will remain. In particular, efforts to maintain or increase forest carbon stocks can lead to numerous benefits, including not only benefits for atmospheric CO_2 (Anderson and Bell, 2009; Anderson *et al*., 2011). Even where there are opportunities, managers face challenges in designing management practices that favor carbon stocks, while at the same time maintaining biodiversity, recognizing the rights of indigenous people, and contributing to local economic development (Food and Agriculture Organization, 2012).

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Box 26-2. Wildfires

Wildfire is a natural process, critical to nutrient cycling, controlling populations of pests and pathogens, biodiversity and fire-adapted species (Bond and Van Wilgen, 1996). However, since the mid-1980s large wildfire activity in North America has been marked by increased frequency and duration, and longer wildfire seasons (Westerling *et al*., 2006; Williamson *et al*., 2009). Recent wildfires in western Canada, the US and Mexico relate to long and warm spring and summer droughts, particularly when they are accompanied by winds (Holden *et al*., 2007; Comisión

Nacional Forestal, 2012b). Interacting processes such as land-use changes associated with the expansion of settlements and activities in peri-urban areas or forested areas, combined with the legacies of historic forest management that prescribed fire suppression, also substantially increase wildfire risk (Radeloff *et al*., 2005; Peter *et al*., 2006; Theobald and Romme, 2007; Fischlin *et al*., 2007; Gude *et al*., 2008; Collins and Bolin, 2009; Hammer *et al*., 2009; Brenkert-Smith, 2010).

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 trends vary across regions (Groisman *et al*., 2007; Girardin *et al*., 2012): the western US has experienced drier conditions since the 1970s (Peterson *et al*., 2013); drought periods in Alberta and Idaho have coincided with large burned areas (Pierce and Meyer, 2008; Kulshreshtha, 2011); heterogeneous patterns of drought severity and a reduction of wildfire risk have been detected for the circumboreal region (Girardin *et al*., 2009). Decadal climatic oscillations also contribute to differences in drought, and thus in wildfire occurrences. The areas burned in the continent boreal forest and in northwest and central Mexico correlate to the dynamics of seasonal land/ocean temperature variability (Macias Fauria and Johnson, 2006; Skinner *et al*., 2006; Villers-Ruíz and Hernández-Lozano, 2007; Macias Fauria and Johnson, 2008; Girardin and Sauchyn, 2008); which is shifting toward hotter temperatures and longer droughts. Such human practices as slash-and-burn agriculture can have negative impacts on Mexican forests (Bond and Keeley, 2005; Comisión Nacional de Áreas Naturales Protegidas and The Nature Conservancy, Programa México, 2009).

Drought index projections and climate change regional models show increases in wildfire risk during the summer and fall on the southeast Pacific coast, Northern Plains and the Rocky Mountains (Liu *et al*., 2012). In places like Sierra Nevada, mixed conifer forests, which have a natural cycle of small, non-crown fires, are projected to have massive crown-fires (Bond and Keeley, 2005) (Table 26-1).

While healthy forests (Davis, 2004) and many fire-maintained systems that burn at lower intensities can provide carbon sequestration and thus mitigation co-benefits (e.g., Longleaf pine savanna, Sierra mixed-conifer)(Fried *et al*., 2008; North *et al*., 2012), forests affected by pests and fires are less effective carbon sinks, and wildfires themselves are a source of emissions.

Wildfires pose a direct threat to human lives, property and health. 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 (Centre for Research on the Epidemeology of Disasters, 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). Wildfire activity causes impacts on human health (section 26.6).

Minimizing adverse effects of wildfires involves short-term and long-term strategies such as planned manipulation of vegetation composition and stand structure (Girardin *et al*., 2012; Terrier *et al*., 2013), suppression of fires where required, fuel treatments, use of fire-safe materials in construction, community planning, and reduction of arson. Not all negative consequences of fire can be avoided, though a mixture of techniques can be used to minimize adverse effects (Girardin *et al*., 2012). 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 US have encouraged reduction of flammable vegetation around structures with different levels of success (Stewart *et al*., 2006). However, such efforts depend largely on land-use planning, 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 affected populations (McFarlane, 2006; Repetto, 2008; Collins and Bolin, 2009; Martin *et al*., 2009; Trainor *et al*., 2009; Brenkert-Smith, 2010). Indigenous peoples are at higher risk from wildfire and may have unique requirements for adaptation strategies (Carroll *et al*., 2010; Christianson *et al*., 2012a; Christianson *et al*., 2012b).

Effective forest management requires stakeholder involvement and investment. The provision of adequate information on smoke, prescribed fire, 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). Institutional shifts from reliance on historical records toward incorporation of climate forecasting in forest management is also crucial to effective adaptation (McKenzie *et al.*, 2004; Millar *et al.*, 2007; Kolden and Brown, 2010).

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26.5. Agriculture and Food Security

Projected declines in global agricultural productivity (Chapter 7) have implications for food security among North Americans. Because North America is a major exporter (Food and Agriculture Organization, 2009; Schlenker and Roberts, 2009), shifts in agricultural productivity here may have implications for global food security. Canada and the US are relatively food secure, although households living in poverty are vulnerable. 17.6% of Mexicans are food insecure (Monterroso *et al.*, 2012). Indigenous peoples are highly vulnerable due to high reliance on subsistence (Chapter 12). While this section focuses on agricultural production, food security is related to multiple factors (See Chapter 7).

26.5.1. Observed Climate Change Impacts

Historic yield increases are attributed in part to increasing temperatures in Canada and higher precipitation in the US (Pearson *et al.*, 2008; Sakurai *et al.*, 2011; Nadler and Bullock, 2011); (high agreement, medium evidence), although multiple non-climatic factors affect historic production rates. In many North American regions optimum temperatures have been reached for dominant crops, thus continued regional warming would diminish rather than enhance yields (Jones *et al.*, 2005) (high confidence). Regional yield variances over time have been attributed to climate variability –e.g., Ontario (Cabas *et al.*, 2010) and Quebec (Almaraz *et al.*, 2008). Since 1999 a marked increase in crop losses attributed to climate-related events such as drought, extreme heat and storms has been observed across North America (Hatfield *et al.*, 2013), with significant negative economic effects (Swanson *et al.*, 2007; Chen and McCarl, 2009; Costello *et al.*, 2009) (high confidence). In Mexico, agriculture accounted for 80% of weather-related financial losses since 1990 (Saldaña-Zorrilla, 2008) (Figure 26-2).

26.5.2. Projected Climate Change Risks

Studies project productivity gains in northern regions and where water is not projected to be a limiting factor, across models, time frames and scenarios (Hatfield *et al.*, 2008; Pearson *et al.*, 2008; Wheaton *et al.*, 2010; Stöckle *et al.*, 2010); (high confidence). Overall yields of major crops in North America are projected to decline modestly by mid-century and more steeply by 2100 among studies that do not consider adaptation (very high confidence). Certain regions and crops may experience gains in the absence of extreme events, and projected yields vary by climate model (Paudel and Hatch, 2012; Liu *et al.*, 2013).

Among studies projecting yield declines, two factors stand out: exceedance of temperature thresholds, and water availability. Yields of several important North American agriculture sectors—including grains, forage, livestock and dairy—decline significantly above temperature thresholds (Wolfe *et al.*, 2008; Schlenker and Roberts, 2009; Craine *et al.*, 2010) Temperature increases affect 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).

Projected temperature increases would reduce corn, soy and cotton yields by 2020, with declines ranging from 30-82% by 2099 depending on crop and scenario (steepest decline for corn, A1) (Schlenker and Roberts, 2009). Studies also project increasing inter-annual yield variability over time (Sakurai *et al.*, 2011; Urban *et al.*, 2012). Several studies focus on California, one of North America's most productive agricultural regions. Modest and variable yield changes among several California crops are projected to 2026, with yield declines from 9-29% by 2097 (A2, DAYCENT model). (Lobell and Field, 2011; Lee *et al.*, 2011) found little negative effect for California perennials by 2050 due to projected climate change, assuming irrigation access (GCM ensemble, A2 and B1). (Hannah *et al.*, 2013), however, project large declines in land suitability for California viticulture by 2050 (with increases further north) with RCPs 4.5 and 8.5 (GCM ensemble); declines greater under RCP 8.5. Heat-induced livestock stress, combined with reduced forage quality, would reduce milk production and weight gain in cattle (Wolfe *et al*., 2008; Hernandez *et al*., 2011).

Precipitation increases off-set but do not 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*., 2011).

Projected change in climate will reduce soil moisture and water availability in the US Western/Southwest, the Western Prairies in Canada, and central and northern Mexico (Pearson *et al*., 2008; U.S. Global Change Research Program, 2009; Cai *et al*., 2009; Esqueda *et al*., 2010; Vano *et al*., 2010b; Kulshreshtha, 2011) (very high confidence). CMIP5 models indicate soil moisture decreases across the continent in Spring and Summer under RCP8.5, with high agreement (Dirmeyer *et al*., 2013). Based on a combined exposure/consumptive water use model, the US Great Plains is identified as one of four global future vulnerability hotspots for water availability from the 2030s and beyond, where anticipated water withdrawals would exceed 40% of freshwater resources (Liu *et al*., 2013). In western US and Canada, projected earlier Spring snowmelt and reduced snowpack would affect productivity negatively regardless of precipitation, as water availability in Summer and Fall are reduced (Schlenker *et al*., 2007; Forbes *et al*., 2011; Kienzle *et al*., 2012).

Projected increases in extreme heat, drought and storms affect productivity negatively (Chen and McCarl, 2009; Kulshreshtha, 2011). The northeastern and southeastern US have been identified as "vulnerability hotspots" for corn and wheat production respectively by 2045 with vulnerability worsening thereafter, using a combined drought exposure and adaptive capacity assessment, with only slight differences between A1B and B2 scenarios (Fraser *et al*., 2013). Central North America is identified as among the globe's regions of highest risk of heat stress by 2070 (NIES GCM; A1B) (Teixeira *et al*., 2013).

26.5.3. A Closer Look at Mexico

Much of Mexico's landbase is already marginal for two of the country's major crops: corn and beef (Buechler, 2009). Severe desertification in Mexico due to non-climate drivers further compromises productivity (Huber-Sannwald *et al*., 2006). Land classified suitable for rain-fed corn is projected to decrease from 6.2% currently to between 3% and 4.3% by 2050 (UKHadley B2, ECHAM5/MPI A2) (Monterroso Rivas *et al*., 2011). 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). Precipitation declines of 0-30% are projected over Mexico by 2040; with the most acute declines in Northwestern Mexico, the primary region of irrigated grain farming (declines steeper in A2 than A1B (18 model ensemble).

Although projected increases in precipitation may contribute to increase in rangeland productivity in some regions (Monterroso Rivas *et al*., 2011), a study in Veracruz indicates that the effects of projected maximum summer temperatures on livestock heat stress are expected to reach the "Danger level" (at which losses can occur) by 2020 and continue to rise (A2, B2, three GCMs) (Hernandez *et al*., 2011). Coffee, an economically important crop supporting 500,000 primarily indigenous households (González Martínez, 2006), is projected to decline 34% by 2020 in Veracruz if historic temperature and precipitation trends continue (Gay *et al*., 2006); see also (Schroth *et al*., 2009), on declines in Chiapas).

Many of Mexico's agricultural communities are also considered highly vulnerable, due to high sensitivity and/or low adaptive capacity (Monterroso *et al*., 2012). The agriculture sector here consists primarily of small farmers (Claridades Agropecuarias 2006), who face high livelihood risks due to limited access to credit and insurance (Eakin and Tucker, 2006; Wehbe *et al*., 2008; Saldaña-Zorilla and Sandberg, 2009; Walthall *et al*., 2012).

26.5.4. Adaptation

The North American agricultural industry has the adaptive capacity to off-set projected yield declines and capitalize on opportunities under 2° warming. (Butler and Huybers, 2012) project a reduction in US corn yield loss from 14% to 6% with 2° warming, with spatial shifts in varietal selection (not accounting for variability in temperature and precipitation). Incremental strategies, such as planting varieties better suited to future climate conditions and changing planting dates, have been observed across the continent (Bootsma *et al*., 2005; Conde *et al*., 2006; Eakin and Appendini, 2008; Coles and Scott, 2009; Nadler and Bullock, 2011; Paudel and Hatch, 2012; Campos *et al*., 2013). In some sectors we are seeing multi-organizational investments in adaptation. International coffee retailers and non-governmental organizations, for example, are engaged in enhancing coffee farmers' adaptive capacity (Schroth *et al*., 2009; Soto-Pinto and Anzueto, 2010). Other strategies specifically recommended for Mexico include soil remediation; improved use of climate information; rainwater capture and drip irrigation (Sosa-Rodriguez, 2013). New crop varieties better suited to future climates, including GMOs, are under development in the US (e.g. (Chen *et al*., 2012), although potential risks have been noted (Quist and Chapela, 2001). Current trends in agricultural practices in commercial regions such as the Midwestern US, however, amplify productivity risks posed by climate change (Hatfield *et al*., 2013). Incremental strategies will have reduced effectiveness under a 2099/4°C warming scenario, which would require more systemic adaptation, including production and livelihood diversification (Howden *et al*., 2007; Mehta *et al*., 2013; Smith and Gregory, 2013; Asseng *et al*., 2013).

Some adaptive strategies impose financial costs and risks onto producers (Craine *et al*., 2010;Wolfe *et al*., 2008), which may be beyond the means of smallholders (Mercer *et al*., 2012) or economically precluded for low-value crops. Technological improvements improve yields under normal conditions but do not protect harvests from extremes (U.S. Global Change Research Program, 2009;Wittrock *et al*., 2011). Others may have maladaptive effects (e.g. increased groundwater and energy consumption). Crop-specific weather index insurance, for example (widely implemented in Mexico to support small farmers), may impose disincentives to invest in diversification and irrigation (Fuchs and Wolff, 2010).

Many strategies have co-benefits, however, in fact investments in agricultural adaptation represent a cost-effective mitigation strategy (Lobell *et al*., 2013). Low- and no-till practices reduce soil erosion and runoff, protect crops from extreme precipitation (Zhang and Nearing, 2005), retain soil moisture, reduce biogenic and geogenic greenhouse gas emissions (Nelson *et al*., 2009; Suddick *et al*., 2010), and build soil organic carbon (Aguilera *et al*., 2013). Planting legumes and weed management on pastures enhance both forage productivity and soil carbon sequestration (Follett and Reed, 2010). Shade perennials increase soil moisture retention (Lin, 2010) and contribute to local cooling (Georgescu *et al*., 2011). Crop diversification mediates the impacts of climate and market shocks (Eakin and Appendini, 2008) and enhances management flexibility (Chhetri *et al*., 2010).

Barriers and Enablers

Market forces and technical feasibility alone are insufficient to foster sectoral-level adaptation (Kulshreshtha, 2011). Institutional support is key, found to be inadequate in many contexts (Bryant *et al*., 2008; Klerkx and Leeuwis, 2009; Jacques *et al*., 2010; Tarnoczi and Berkes, 2010; Brooks and Loevinsohn, 2011; Alam *et al*., 2012; Anderson and McLachlan, 2012)(high confidence). Even many suggested adaptation strategies with anticipated economic benefits are often not adopted by farmers, suggesting the need for more attention to culture and behavior (Moran *et al*., 2013). Attitudinal studies among US farmers indicate limited acknowledgement of anthropogenic climate change, associated with lower levels of support for adaptation (Arbuckle Jr *et al*., 2013; Gramig *et al*., 2013) (high agreement, medium evidence).

Other key enablers are access to and quality of information (Tarnoczi and Berkes, 2010; Tarnoczi, 2011; Baumgart-Getz *et al*., 2012; Tambo and Abdoulaye, 2012), particularly regarding optimum crop management, production inputs and optimum crop-specific geographic information. Social networks are important for information dissemination and farmer support (Chiffoleau, 2009; Wittrock *et al*., 2011; Baumgart-Getz *et al*., 2012). Networks among producers may be especially important to the level of awareness and concern farmers hold about climate change(Frank *et al*., 2010; Sánchez-Cortés and Chavero, 2011), while also enabling extensive farmer-to-farmer exchange of adaptation strategies (Eakin *et al*., 2009).

26.6. Human Health

Large national assessments of climate and health have been carried out in the US and Canada (Belanger *et al*., 2008a) (see references in 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, vulnerability and health. The causal pathways leading from climate to health are complex, and can be modified by 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 Climate Action Council, 2012).

26.6.1. Observed Impacts, Vulnerabilities and Trends

26.6.1.1. Storm-Related Impacts

The magnitude of health impacts of extreme storms depends on interactions between exposure and characteristics of the affected communities (Keim, 2008). Coastal and low-lying infrastructure and populations can be vulnerable due to flood-related interruptions in communications, healthcare access, and mobility. Health impacts can arise through direct pathways of traumatic death and injury (e.g., drowning, impacts of blowing and falling objects; contact with power wires) as well as more indirect, longer-term pathways related to damage to health and transportation infrastructure, 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 can arise due to the stress of evacuation, property damage, economic loss, and household disruption (Weisler *et al*., 2006; Gamble *et al*., 2008; Berry *et al*., 2010; Bethel *et al*., 2011). Since 1970, there has been no clear trend in US hurricane deaths, once the singular Katrina event is set aside (Blake *et al*., 2007).

26.6.1.2. Temperature Extremes

Studies throughout North America have shown that high temperatures can increase the mortality and/or morbidity (e.g., Medina-Ramon and Schwartz, 2007; Kovats and Hajat, 2008; O'Neill and Ebi, 2009; Anderson and Bell, 2009; Knowlton *et al*., 2009; Deschenes *et al*., 2009; Kenny *et al*., 2010; Hajat and Kosatsky, 2010; Cueva-Luna *et al*., 2011; Hurtado-Díaz *et al*., 2011; Romero-Lankao *et al*., 2012b). 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). To date, trends over time in cold-related deaths have not been investigated. Most available NA evidence derives from the US and Canada, though one study reported significant heat- and cold-related mortality impacts in Mexico City (McMichael *et al*., 2008). US EPA has tracked the death rate in the US from 1979 to 2009 for which death certificates list the underlying cause of death as heat related (U.S. Environmental Protection Agency, Office of Atmospheric Programs, 2012). No clear trend upwards or downwards is yet apparent in this indicator. Note that this case definition is thought to significantly underestimate the total impacts of heat on mortality.

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*., 2013b). 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). Although air pollution emission trends will play a dominant role in future pollution levels, climate change may make it harder to achieve some air quality goals (Jacob and Winner, 2009). Forest fire is a source of particle emissions in NA, and can lead to increased cardiac and respiratory-disease 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 (Potera, 2011). Climate variability and change will affect indoor air quality, but with direction and magnitude that remains largely unknown (Institute of Medicine, 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 affect production of many types of tree and grass pollen (Reiss and Kostic, 1976; Minero *et al*., 1998; Lo and Levetin, 2007; U.S. Environmental Protection Agency, 2008). Ragweed pollen production is responsive to temperatures and to CO_2 concentrations (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, pollen exposure and allergic disease morbidity could change in response to climate change. However, to date, the timing of the pollen season is the only evidence for observed climate-related impacts. 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). Ragweed season length has increased at some monitoring stations in the United States (Ziska *et al*., 2011). Research on trends in NA has been hampered by the lack of long-term, consistently collected pollen records (U.S. Environmental Protection Agency, 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 US and Canadian outbreaks include legionella bacterium, the cryptosporidium parasite, campylobacter, and giardia (Belanger *et al*., 2008b; Center for Disease Control and Prevention, 2011). 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 immune-compromised 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 temperature and hydrological cycles can influence the risk of waterborne diseases (Curriero *et al*., 2001; Greer *et al*., 2008; Harper *et al*., 2011). Severe storms have been shown to play a role in water-borne disease risks in Canada (Thomas *et al*., 2006). Floods enhance the potential for runoff to carry sediment and pollutants to water supplies (Karl *et al*., 2008). 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, climate variability on a daily, seasonal or interannual scale may result in organism adaptation and shifts, though not necessarily expansion, in geographic range (Lafferty, 2009; Tabachnick, 2010; McGregor, 2011). Range shifts 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; Kolivras, 2010; Degallier *et al*., 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. Risk is increasing from invasive vector-borne pathogens, such as chikungunya (Ruiz-Moreno *et al*., 2012) and Rift Valley fever viruses (Greer *et al*., 2008). There is also potential risk from invasive vector-borne pathogens, such as chikungunya (Ruiz-Moreno *et al*., 2012) and Rift Valley fever viruses (Greer *et al*., 2008). Mexico is listed as high risk for dengue fever by the WHO. There has been an increasing number of cases of Lyme disease in Canada and Lyme disease vectors are spreading along climate-determined trajectories (Leighton *et al*., 2012; Koffi *et al*., 2012).

26.6.2. Projected Climate Change Impacts

Projecting future consequences of climate warming for heat-related mortality and morbidity 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).

Several recent studies have projected future health impacts due to air pollution in a changing climate (Knowlton *et al*., 2004; Bell *et al*., 2007; Tagaris *et al*., 2009; Tagaris *et al*., 2010; Chang *et al*., 2010). There is a large literature examining future climate influences on outdoor air quality in North America, particularly for ozone (Murazaki and Hess, 2006; Steiner *et al*., 2006; Tao *et al*., 2007; Kunkel *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, 2009). However, analyses show that future increases can be offset through measures taken to limit emission of pollutants (Kelly *et al*., 2012). The literature for PM2.5 is more limited than that for ozone, and shows a more complex pattern of climate sensitivities, with no clear net influence of warming temperatures (Liao *et al*., 2007; Tagaris *et al*., 2008; Avise *et al*., 2009; Pye *et al*., 2009; Mahmud *et al*., 2010). On the other hand, $PM_{2.5}$ plays a crucial role. Regarding outdoor pollen, warming will lead to further changes in the seasonal timing of pollen release (high confidence). Another driver of future pollen could be changing spatial patterns of vegetation as a result of climate change.

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 research gaps 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 events like heat waves, storms and floods (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). Adaptation planning at all scales to build resilience for health systems in the face of a 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 with implementation of warning and response systems (Romero-Lankao *et al*., 2012b). 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).

26.7. Key Economic Sectors and Services

There is mounting evidence that many economic sectors across North America have experienced climate impacts and are adapting to the risk of loss and damage from weather perils. This section covers the literature for the energy, transportation, mining, manufacturing, construction and housing, and insurance sectors in North America. Recent studies find 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. Energy

26.7.1.1. Observed Impacts

Energy demand for cooling has increased as building stock and air conditioning penetration have increased (Wilbanks *et al*., 2012). Extreme weather currently poses risk to the energy system (Wilbanks *et al*., 2012). For example, Hurriacne Sandy results in a loss of power to 8.5 million customers in the Northeast US (National Oceanic and Atmospheric Administration, 2013). Energy consumption is a major user of water resources in North America, with 49% of the water withdrawals in the US for thermoelectric power (Kenny *et al*., 2009).

26.7.1.2. Projected Impacts

Demand for summer cooling is projected to increase and demand for winter heating is projected to decrease. Total energy demand in North America is projected to increase in coming decades because of non-climate factors (Galindo, 2009; National Energy Board, 2011; Energy Information Administration, 2013). Climate change is projected to have varying geographic impacts. In Canada, a net decrease in residential annual energy demand is projected by 2050 and by 2100 (Isaac and Van Vuuren, 2009; Schaeffer *et al*., 2012). It is difficult to project changes in net energy demand in the US because of uncertainties in such factors as climate change, and change in technology, population, and energy prices. Peak demand for electricity is projected to increase more than the average demand for electricity, with capacity expansion needed in many areas (Wilbanks *et al*., 2012). Given the projected increases in energy demand in the southern United States from climate change (Auffhammer and Aroonruengsawat, 2011; Auffhammer and Aroonruengsawat, 2012) it is reasonable to conclude that Mexico will have a net increase in demand.

Major water resource related concerns include effects of increased cooling and other demands for water and water-scarcity in the west; effects of extreme weather events, sea-level rise, hurricanes, and seasonal droughts in the southeast; and effects of increased cooling demands in the northern regions (Wilbanks *et al.*, 2008; Wilbanks *et al.*, 2012; McDonald, 2012; U.S. Department of Energy, 2013) .

The magnitude of projected impacts on hydropower potential will vary significantly between regions and within drainage basins(Desrochers *et al.*, 2009; Shrestha *et al.*, 2012; Kienzle *et al.*, 2012). Annual mean hydropower production in the Peribonka River in Quebec is estimated to increase by approximately 10% by mid-century and 20% late in the century under the A2 scenario (Minville *et al.*, 2009).

Higher temperatures and increased climate variability can have adverse impacts on renewable energy production such as wind and solar (U.S. Department of Energy, 2013). Changing cloud cover affects solar energy resources, changes in winds affect wind power potentials, and temperature change and water availability can affect biomass production (Wilbanks *et al.*, 2008; U.S. Department of Energy, 2013) .

26.7.1.3. Adaptation

Many adaptations are underway to reduce vulnerability of the energy sector to extreme climate events such as heat, drought, and flooding (U.S. Department of Energy, 2013). Adaptation includes many approaches such as increased supply and demand efficiency (e.g., through more use of insulation), more use of urban vegetation and reflective surfaces, improved electric grid, reduced reliance on above ground distribution systems, and distributed power (Wilbanks *et al.*, 2012). Important barriers to adaptation include uncertainty about future climate change, inadequate information on costs of adaptation, lack of climate resilient energy technologies, and limited price signals (U.S. Department of Energy, 2013). Strategies resulting in energy demand reduction would reduce greenhouse gas emissions and reduce the vulnerability of the sector to climate change.

26.7.2. Transportation

26.7.2.1. Observed Impacts

Much of the transportation infrastructure across North America is aging, or inadequate (Mexico) which may make it more vulnerable to damage from extreme events and climate change. Approximately 11% of all US bridges are structurally deficient, 20% of airport runways are in fair or poor condition, and more than half of all locks are more than 50 years old (US Department of Transportation 2013). More than US$2 trillion is needed to bring infrastructure in the US up to “good condition” (American Society of Civil Engineers, 2009) p. 6. Canadian infrastructure had an investment deficit of C$125 billion in the 1980s and 1990s (Mirza and Haider, 2003).

Some transportation systems have been harmed (Figure 26-2). For example, in 2008, Hurricane Ike caused $2.4 billion in damages to ports and waterways in Texas. (McDonald, 2012). The “superflood” in Tennessee and Kentucky in 2010 caused $2.3 billion in damage (National Oceanic and Atmospheric Administration, 2013).

Hurricane Sandy resulted in flooding of portions of New York City’s subway system, overtopping of runways at La Guardia airport, and caused $400 million in damage to the New Jersey transit system (National Oceanic and Atmospheric Administration, 2013).

26.7.2.2. Projected Impacts

Scholarship on projected climate impacts on transportation infrastructure focuses mostly on US and Canada. Increases in high temperatures, 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 less ice cover (Transportation Research Board, 2008). A 1-meter sea level rise combined with a 7-meter storm surge could inundate over half of the highways, arterials, and rail lines in the US Gulf coast (Savonis *et al*., 2008). Declining water levels in the Great Lakes would increase shipping costs by restricting vessel drafts and reducing vessel cargo volume (Millerd, 2011). In southern Canada by the 2050s, cracking of roads from freeze and thaw would decrease under the B2 and A2 scenarios, structures would freeze later and thaw earlier, while higher extreme temperatures could increase 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$2 to US$3 billion per year by 2050 (Chinowsky *et al*., 2013). Tens of thousands to more than 100,000 bridges in the US could be vulnerable to increasing peak river flows in the mid- and late-21st Century under the A1B and A2 scenarios. Strengthening vulnerable bridges to be less vulnerable to climate change is estimated to cost approximately US$100 to $250 billion (Wright *et al*., 2012).

26.7.2.3. Adaptation

Adaptation steps are being taken in North America, particularly to protect transportation infrastructure from sea level rise and storm surge in coastal regions. Almost all of the major river and bay bridges destroyed by Hurricane Katrina surge waters were rebuilt at higher elevations, and the design of the connections between the bridge decks and piers were strengthened (Grenzeback and Luckmann, 2006).

Adaptation actions include protecting coastal transportation from sea level rise and more intense coastal storms or possibly relocating infrastructure. Many Midwestern states are examining channel protection and drainage designs, while transportation agencies in Canada and the United States have been preparing to manage the aftermath of extreme weather events (Meyer *et al*., 2013). In addition, new materials may be needed so pavement and rail lines can better withstand more extreme temperatures.

26.7.3. Mining

26.7.3.1. 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*., 2010a; Locke *et al*., 2011; Gómez-álvarez *et al*., 2011; Kirchner *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 (from metals, sulfate and acid) at three mine sites in the United States were measured during rainstorm events following dry periods (Nordstrom, 2009).

26.7.3.2. Projected Impacts

Climate change is perceived by Canadian mine practitioners as an emerging risk, and in some cases, a potential opportunity (Ford *et al*., 2010a; Ford *et al*., 2011; Pearce *et al*., 2011; National Round Table on the Environment and the Economy, 2012), with potential impacts on transportation (Ford *et al*., 2011) and limited water availability (Acclimatise, 2009) from projected drier conditions (Sun *et al*., 2008; Seager and Vecchi, 2010) being identified as key issues.

An increase in heavy precipitation events projected for much of North America (Warren and Egginton, 2008; Nordstrom, 2009) would adversely affect the mining sector. A study on acid rock damage drainage in Canada concluded that an increase in heavy precipitation events presented a risk of both environmental impacts and economic costs (Stratos Inc, 2011) Damage to mining infrastructure from extreme events, for active and post-operation mines, is also a concern (Pearce *et al*., 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).

26.7.3.3. Adaptation

Despite increasing awareness, there are presently few documented examples of proactive adaptation planning within the mining sector (Acclimatise, 2009; Ford *et al*., 2010a; Ford *et al*., 2011). However, adjustments to management practices to deal with short-term water shortages, including reducing water intake, increasing recycling and establishing infrastructure to move water from tailing ponds, pits and quarries, have worked successfully in the past (Chiotti and Lavender, 2008). Integrating climate change considerations at the mine planning and design phase increases the opportunity for effective and cost-efficient adaptation (Stratos Inc, 2011).

26.7.4. Manufacturing

26.7.4.1. 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 US (Lazo *et al*., 2011). Weather affects the supply of raw material, production process, transportation of goods, and 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 drought in Texas led to a decision to close a beef processing plant (Beef Today Editors, 2013). Drought also caused delays for barge shipping on the Mississippi River in 2012 (Reuters, 2012). Major storms, like Hurricanes Sandy, Katrina and Andrew, significantly disrupted manufacturing activities, including plant shutdowns due to direct damages and/or loss of electricity and supply disruptions due to unavailability of parts, and difficulties delivering products due to compromised transportation networks (Baade *et al*., 2007; Dolfman *et al*., 2007).

26.7.4.2. Projected Impacts

The drier conditions (Sun *et al*., 2008; Seager and Vecchi, 2010; 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 operations. A study of the effect of changes in precipitation (A1B scenario) on 70 industries in the US between 2010 and 2050 found potentially significant losses in production and employment due to declines in water availability and the interconnectedness of different industries (Backus *et al*., 2013).

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 occupational health risks (e.g., Kjellstrom *et al*., 2009; Hanna *et al*., 2011; Kjellstrom and Crowe, 2011).

26.7.4.3. Adaptation

Some companies are beginning to recognize the risks climate change presents to their manufacturing operations, and consider strategies to build resilience (National Round Table on the Environment and the Economy, 2012). Coca Cola has a water stewardship strategy focusing 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). Air conditioning is a viable and effective adaptation option to address some of the impacts of warming, though it does incur greater demands for electricity and additional costs (Scott *et al*., 2008a). Sourcing raw materials from different regions and relocating manufacturing plants are other adaptation strategies that can be used to increase resiliency and reduce vulnerability.

26.7.5. Construction and Housing

26.7.5.1. Observed Impacts

The risk of damage from climate change is important for construction industries, though little research has systematically explored the topic (Morton *et al*., 2011). Private data from insurance companies report a significant increase in severe weather damage to buildings and other insured infrastructure over several decades (Munich Re, 2012).

26.7.5.2. Projected Impacts

Most studies project a significant further increase in damage to homes, buildings and infrastructure (Bjarndadottir *et al*., 2011; IPCC, 2012). Affordable adaptation in design and construction practices could reduce much of the risk of climate damage for new buildings and infrastructure, involving reform in Building Codes and other standards (Feltmate and Thistlethwaite, 2012). 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.

26.7.5.3. 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; Insurance 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 (Levina *et al*., 2007; Kunreuther and Michel-Kerjan, 2009; Insurance Institute for Business and Home Safety, 2011), 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 has 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).

26.7.6. Insurance

26.7.6.1. 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; Munich Re, 2011; Bresch and Spiegel, 2011). Most of the increase in insurance claims paid 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 (IPCC, 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. Discounts have been introduced where investments in adaptation have reduced the risk of future weather losses (Mills, 2012). Further detailed discussion on the insurance sector and climate change can be found in section 10.7.

26.7.6.2. Projected Impacts

Without adaptation, there is an expectation that severe weather insurance damage claims would 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; Balshi *et al.*, 2009), and other perils in frequency, including intense rainfall events (IPCC, 2012).

26.7.6.3. Adaptation

The insurance industry is one of the most studied sectors in North America in terms of climate impacts and adaptation. Most adaptation in the insurance industry has been in response to an increase in severe weather damage, with little evidence of proactive adaptation in anticipation of future climate change (Mills and Lecomte, 2006; Mills, 2007; Mills, 2009; Kunreuther and Michel-Kerjan, 2009; Leurig, 2011; Autorite des Marches Financiers, 2011; Gallagher, 2012). In addition to pricing decisions based on an actuarial analysis of historic loss experience, many insurance companies in the United States and Canada now use climate 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 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 (von Peter *et al.*, 2012). Government insurance programs for coverage of flood in the United States have been affected by recent hurricanes and previously subsidized premiums have been changed to more accurately reflect risk (Federal Emergency Management Agency, 2013). 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 2012, per capita spending on property and casualty insurance was US$2,239.20 in the United States, US$2,040.40 in Canada, and US$113.00 in Mexico (Seiler *et al.*, 2013).

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, in 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.

26.8. Urban and Rural Settlements

Recently a growing body of literature and national assessments have focused on climate-related impacts, vulnerabilities and risks in North American settlements (e.g., US-NCA chapters 11 and 14 and AR5 chapters 8 and 9).

26.8.1. Observed Weather and Climate Impacts

Observed impacts on lives, livelihoods, economic activities, infrastructure and access to services in North American human settlements have been attributed to sea level rise (26.2.2.1), changes in temperature and precipitation, and occurrences of extreme events like heat waves, droughts and storms (Figure 26-2).

Only a handful of these impacts have been attributed to anthropogenic climate change, such as shifts in Pacific Northwest marine ecosystems, which have restricted fisheries and thus affected fishing communities (U.S. Global Change Research Program, 2009). As well, (MacKendrick and Parkins, 2005; Parkins and MacKendrick, 2007; Parkins, 2008; Holmes, 2010) identified 30 communities and 25,000 families in British Columbia negatively affected by the mountain pine beetle outbreak (See 26.4.1.1).

While *droughts* are among the more notable extreme events affecting North American urban and rural settlements recently, with severe occurrences in the Canadian Prairies causing economic and employment losses (2001-2), changes in drought frequency in North America have not been attributed to anthropogenic climate change (Figure 26-1). The 2010-2012 drought across much of the US and Northern Mexico was considered the most severe in a century (MacDonald, 2010). It affected 80% of agricultural land in the US, with 2,000 counties designated disaster zones by September (U.S. Department of Agriculture, Economic Research Service, 2012). Impacts include the loss of 3.2 million tons of maize in Mexico, placing 2.5 million at risk of food insecurity (Direccion General de Comunicacion Social, 2012). Among the most severely affected were indigenous peoples, such as the Rarámuri of Chihuahua (ibid.). Closely associated with droughts, the impacts of recent wildfires have been significant (See Box 26.2), and have intensified inequalities in vulnerability between amenity migrants and low-income residents in peri-urban areas of California and Colorado (Collins and Bolin, 2009).

Other extreme-events include *heat-waves*, resulting in excess urban mortality (O'Neill and Ebi, 2009; Romero-Lankao *et al.*, 2012b); and affecting infrastructure and built environments –e.g., road pavement in Chicago buckled under temperatures over 100ºF (CBS Chicago, 2012); in Colorado two wildfires burned over 600 homes (National Climate Data Center, 2013).

Extreme storms and extreme precipitation have also impacted several North American regions (Figures 26-1 and 26-2). Flood frequency has increased in some cities, a trend sometimes associated with more intense precipitation (e.g., Mexico City and Charlotte NC, US) (Villarini *et al.*, 2009; Magana, 2010), while in others this trend is associated with a transition from flood events dominated by snowmelt to those caused by warm-season thunderstorms (e.g., Québec, Canada and Milwaukee, US) (Ouellet *et al.*, 2012; Yang *et al.*, 2013). As illustrated by Sandy (Neria and Shultz, 2012; Powell *et al.*, 2012), storms impact human health and healthcare access (section 26.6.1.1), and impacts on infrastructure and the built environment have been costly. Heavy precipitation, storm surges, flash-floods and wind, including flooding on the US East Coast, and Midwest (2011), hurricanes and floods in the city of Villa Hermosa (Comisión Económica para América Latina y el Caribe,) and other urban areas in southern Mexico (2004-5), have compromised homes and businesses (Comfort, 2006; Kirshen *et al.*, 2008; Jonkman *et al.*, 2009; Romero-Lankao, 2010). Hurricane Wilma alone caused $1.8 billion in damage, among the biggest insurance losses in Latin American history (Galindo *et al.*, 2009).

The impacts of interacting hazards compound vulnerabilities (26.8.2). Coastal settlements are at risk from the combined occurrence of coastal erosion, health effects, infrastructure and economic damage from storm surges. Earlier thaw (Friesinger and Bernatchez, 2010), SLR, and coastal flooding have been detected along the mid-Atlantic, Gulf of Mexico, and St. Lawrence (Kirshen *et al.*, 2008; Zavala-Hidalgo *et al.*, 2010; Friesinger and Bernatchez, 2010; Rosenzweig *et al.*, 2011; Tebaldi *et al.*, 2012).

Climate impacts on the ecosystem-function and -services (e.g., water supplies, biodiversity or flood protection) provided to human settlements are another concern. While acknowledged in some places (e.g., Mexico City Climate Action Plan), they have received relatively less scholarship attention (Hunt and Watkiss, 2011).

26.8.2. Observed Factors and Processes Associated with Vulnerability

Differences in the severity of climate impacts on human settlements are strongly influenced by context-specific vulnerability factors and processes (Table 26.1, Cutter *et al*., 2013), some of which are common to many settlements, while others are more pertinent to some types of settlements than others. Human settlements simultaneously face a multilevel array of non-climate-related hazards (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.

26.8.2.1. Urban Settlements

Hazard risks in urban settlements are enhanced by the *concentration* of populations, economic activities, cultural amenities and built environments particularly when they are in highly-exposed locations such as coastal and arid areas. Cities of concern include those in the Canadian prairies and US-Mexico border region; and major urban areas including Boston, New York, Chicago, Washington DC, Los Angeles, Villa Hermosa, Mexico City and Hermosillo (Comisión Económica para América Latina y el Caribe; Bin *et al*., 2007; Collins, 2008; Kirshen *et al*., 2008; Collins and Bolin, 2009; Gallivan *et al*., 2009; Rosenzweig *et al*., 2010; Hayhoe *et al*., 2010; Romero-Lankao, 2010; Wittrock *et al*., 2011).

Risks may also be heightened by *multiple interacting hazards*. Slow-onset events such as urban heat-islands, for instance, interact with poor air-quality in large North American cities to exacerbate climate impacts on human health (Romero-Lankao *et al*., 2013a). As illustrated by recent weather events (Figure 26.2), however, hazard interactions can also follow individual, high-magnitude extreme events of short duration, with cascading effects across interconnected energy, transportation, water and health infrastructures and services to contribute to and compound urban vulnerability (Gasper *et al*., 2011). Wildfire vulnerability in the southwest has been compounded by peri-urban growth (Collins and Bolin, 2009; Brenkert-Smith, 2010). Under current financial constraints in many cities, climate-related economic losses can reduce resources available to address social issues, thus threatening institutional capacity and urban livelihoods (Kundzewicz *et al*., 2008).

The *urbanization process* and *urban built-environments* of North America can amplify climate impacts as they change land-use and land-surface physical characteristics (e.g., surface albedo, Chen *et al*., 2011a). A 34% increase in US 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 (section 26.3), 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 the aerosol composition of airsheds (Ntelekos *et al*., 2010). The UHI can also increase health risks differentially, due to socio-spatial inequalities across and within North American cities (Harlan *et al*., 2008; Miao *et al*., 2011).

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).

Elements of the *built-environment* such as housing stock, urban form, the 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 many Canadian and US cities are in need of infrastructure adaptation upgrades (Doyle *et al.*, 2008; Conrad, 2010), Mexican cites are faced with existing infrastructure deficits (Niven *et al.*, 2010; Hardoy and Romero Lankao, 2011), and high levels of socio-spatial segregation (Smolka and Larangeira, 2008) (section 26.7).

Recent weather hazards (Figure 26-2) illustrate that economic activities and highly-valued physical capital of cities (real estate, interconnected infrastructure systems) are very sensitive to climate-related disruptions that can result in high impacts; activities in some urban areas are particularly exposed to key resource constraints (e.g., water in the US-Mexico Border; oil industry in Canada, US and Mexico; Levy et al., 2010; Conrad, 2010); 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 also impact the economic performance of cities (Hunt and Watkiss, 2011).

Cities are relatively better endowed than rural populations with individual and neighborhood assets such as income, education, quality of housing and access to infrastructure and services that offer protection from climate hazards. However, intra-urban socio-spatial differences in access to these assets shape response capacities (Harlan and Ruddell, 2011; Romero-Lankao *et al.*, 2013a). All this means that class and socio-spatial segregation are key determinants not only of vulnerability but also of inequalities in risk generation and distribution within cities. 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.*, 2011). 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.*, 2013a), 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). In some cities, 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.*, 2012a).

Although cities have comparatively higher access than rural municipalities to determinants of institutional capacity such as human resources and revenue pools, their governance arrangements are often hampered by jurisdictional conflicts, asymmetries in information and communication access, fiscal constraints on public services including emergency personnel, and top-down decision making. These governance issues exacerbate urban vulnerabilities and constrain urban adaptation planning (Carmin *et al.*, 2012; Romero-Lankao *et al.*, 2013a).

26.8.2.2. Rural Settlements

The legacy of previous and current stresses contributing to rapid population growth or loss in North American rural communities, reduced employment, or degradation of local knowledge systems, can increase vulnerability (Brklacich *et al.*, 2008; Coles and Scott, 2009; McLeman, 2010). 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). US 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 land and many sources of social and human capital (Brklacich *et al.*, 2008; Hardess *et al.*, 2011). Conversely, rural and indigenous community members possess valuable local and experiential knowledge regarding regional ecosystem services (Nakashima *et al.*, 2011).

Rural economies have limited economic diversity and relatively high dependence on climate-sensitive sectors (Johnston *et al.*, 2008; Natural Resources Canada, 2008; Molnar, 2010); they 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). 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. 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 seasonal economies and 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, water, and transportation disruptions associated with hazards.

Geographic isolation can be a key source of vulnerability for rural communities in North America, imposing 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 both cultural and livelihood wellbeing (Andrachuk and Pearce, 2010; Hardess *et al.*, 2011). Many indigenous peoples also 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).

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). A lack of redundant power and communication services can compromise hazard response capacity.

26.8.3. Projected Climate Risks on Urban and Rural Settlements

Urbanization, migration, economic disparity, and institutional capacity will influence future impacts and adaptation to climate change in North American human settlements (section 26.2.1). Water related concerns are assessed in 26.3.2.1 and 26.3.2.3). We describe below a variety of future climate risks identified in the literature, many of which focus on cities (Chapters 8 and 9) and, with the exception of larger centers such as New York and Boston, are qualitative in nature (Hunt and Watkiss, 2011). This is due in part to the difficulty in downscaling the prediction of trends in key trends in climate parameters to an appropriate scale

Model-based *sea-level-rise* (SLR) projections of future risks to cities are characterized by large uncertainties due to global factors (e.g., the dynamics of polar ice-sheets WGI) and regional factors (e.g., regional shifts in ocean circulation, high of the adjacent ocean and local land high) (Blake *et al.*, 2011) (WGI chapter 3). The latter will determine differential SLR impacts on regional land development of coastal settlements (U.S. Government Accountability Office, 2007; Yin *et al.*, 2009; Sobel *et al.*, 2010; Conrad, 2010; Millerd, 2011), making some areas particularly vulnerable to inundation (Cooper and Sehlke, 2012). SLR can also exacerbate vulnerability to extreme events such as hurricanes (Frazier *et al.*, 2010).

Temperature increases would lead to additional health hazards. 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 26.2.2), particularly in northern mid-latitude cities (Jacob and Winner, 2009). Participation in some outdoor activities would also increase as a result of projected increases in warm days (Scott and McBoyle, 2007). Projected snowfall declines in Canada and the Northeast US would reduce length of winter sport seasons and thus affect the economic wellbeing of some communities (McBoyle *et al.*, 2007; Scott *et al.*, 2008b).

Any increase in frequency of *extreme events,* such as intense precipitation, flooding and prolonged dry periods would affect particularly the populations, economic activities, infrastructures and services on coasts, flood-prone deltas and arid regions (Nicholls *et al.*, 2008; Kirshen *et al.*, 2008; Richardson, 2010; Weiss *et al.*, 2011). For example, 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). (Ntelekos *et al.*, 2010; Cayan *et al.*, 2010) project an increase in the number and duration of droughts in the southwest US, with most droughts expected to last over five years by 2050 (GDFL CM2.1 and CNRM CM3, A2 and B1). Assuming no adaptation, total loses from river flooding in metropolitan Boston are estimated to exceed $57 billion by 2100, of which $26 billion is attributed to climate change (Nicholls *et al*., 2008; Kirshen *et al*., 2008; Richardson, 2010; Weiss *et al*., 2011).

Future climate risks on *lives and livelihoods* have been relatively less studied. A handful of studies focused on forestry are notable, indicating potentially substantial shifts in livelihood options without adaptation. Sohngen and Sedjo (Sohngen and Sedjo, 2005) estimate losses from climate change in the Canadian/US 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). Substantial declines in suitable habitat for valued tree species in Mexico have been projected (Gómez-Mendoza and Arriaga, 2007; Gomez-Diaz *et al*., 2011).

Scholars are starting to project future risks from interacting hazards. For instance, by 2070 with a 0.5m rise in sea-level and under scenarios of socioeconomic growth, storm surges and subsidence, populations at risk in New York, Miami and New Orleans might increase three-fold, while asset exposure will increase more than 10-fold (Hanson *et al*., 2011).

Essential *infrastructure and services* are key concerns (sections 26.3 and 26.7). Increased occurrence of drought affecting water availability is projected for southwestern US/Northern Mexico, the southern Canadian Prairies and central Mexico, combined with projected increases in water demand due to rapid population growth and agriculture (Schindler and Donahue, 2006; MacDonald, 2010; Lal *et al*., 2011). Using A1B and A2 scenarios, (Escolero-Fuentes *et al*., 2009) projected that by 2050, Mexico City and its watersheds will experience a more intense hydrological cycle and a reduction of between 10 to 17% in per capita available water. Sea-level rise is predicted to threaten 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

As illustrated by recent extreme events (Figure 26-2), individuals and households in North America have not only be affected by extremes, but have also been responding to climate impacts mostly through incremental actions, for example by purchasing additional insurance, or reinforcing homes to withstand extreme weather (Simmons and Sutter, 2007; Romero-Lankao *et al*., 2012a). Some individuals respond by diversifying livelihoods (Newland *et al*., 2008; Rose and Shaw, 2008) or migrating (See 26.1.1) (Black *et al*., 2011).

The propensity to respond to climate and weather hazards is strongly influenced not only by access to household assets, but also by community and governmental support. The emergency response to Sandy illustrates this. Although New York and New Jersey witnessed vivid scenes of 'medical humanitarianism,' because of inadequate communication and coordination among agencies, public health support did not always reach those most in need (Abramson and Redlener, 2013).

The perceived risks of climate change among individuals are equally important. Strong attachment to place and occupation may motivate willingness to support incremental adaptation, enhance coping capacity and foster adaptive learning (Collins and Bolin, 2009; Romero-Lankao, 2010; Aguilar and Santos, 2011; Wittrock *et al*., 2011). They have also been found to serve as barriers to transformational adaptation (Marshall *et al*., 2012). Residents of the US 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, or support for public investments in adaptation.

26.8.4.1.2. What are governments doing? Planned Adaptation

Leadership in adaptation is far more evident locally than at other tiers of government in North America (Richardson, 2010; Vasseur, 2011; Vrolijks *et al*., 2011; Henstra, 2012; Carmin *et al*., 2012). Few municipalities have moved into the implementation stage, however; most programs are in the process of problem diagnosis and planning (Perkins *et al*., 2007; Moser and Satterthwaite, 2008; Romero-Lankao and Dodman, 2011). 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, suggesting the need for subnational and federal-level facilitation in the form of resources and enabling regulations .

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*., 2013a). Some policies constitute "integrated" strategies (New York) (Perkins *et al*., 2007; Rosenzweig *et al*., 2010), and 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).

26.8.4.2. Opportunities and Constraints

Adaptation in human settlements is influenced by local access to resources, political will and the capacity for institutional-level attention and multilevel/multisectoral coordination (Burch, 2010; Romero-Lankao *et al*., 2013a) (discussed further in the next section).

26.8.4.2.1. Adaptation is path-dependent

Adaptation options are constrained 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. Previous water development, for example, can result in irreversible overexploitation and degradation of water resources.

26.8.4.2.2. Institutional capacity

At all levels of governance, adaptation in North America is affected by numerous determinants of institutional capacity. Three have emerged in the literature as particularly significant challenges for urban and rural settlements:

- *Economic Resources:* Rural communities face limited revenues combined with higher costs of supplying services (Williamson *et al*., 2008; Posey, 2009). Small municipal revenue pools translate into fiscal constraints necessary to support public services, including emergency personnel and health care (Lal *et al*., 2011). Although large cities tend to have greater fiscal capacity, most do not receive financial support for adaptation (Carmin *et al*., 2012), 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*., 2013a). Levels of knowledge and prioritization can be low among municipal planners. 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 climate risk (Wolf *et al*., 2010; Romero-Lankao *et al*., 2012b).

- *Participation:* Considering the overlap among impacts and sources of vulnerability in North American human settlements, long-term effectiveness of local adaptation hinges upon inclusion of all stakeholders. Stakeholder involvement lengthens planning time frames, may elicit conflicts, and power relationships can constrain access (Few *et al*., 2007; Colten *et al*., 2008). However, effective stakeholder engagement has tremendously enhanced adaptation planning, eliciting key sources of information regarding social values, securing legitimacy (Aguilar and Santos, 2011), and fostering adaptive capacity of involved stakeholders.

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Box 26-3. Climate Responses in Three North American Cities

With 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 that climate change is projected 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 (Rosenzweig and Solecki, 2010; Leon and Neri, 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 (Romero-Lankao, 2010; Leon and Neri, 2010; Kinney *et al*., 2011; Solecki, 2012).

The three cities have been frontrunners in the climate arena. 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," with most of designated funds committed to reducing 7 million tonnes of CO_2 equivalent by 2012 (Romero-Lankao *et al*., 2013). New York City's and Vancouver's Plans are similarly mitigation-centred. As of 2007 New-York's long-term sustainability plan included adaptation (Solecki, 2012; Ray *et al*., 2013), while Vancouver launched its municipal adaptation plan 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 unavoidable.

Urban leaders in all three cities have emerged as global leaders in sustainability. Mayor Bloomberg of New York; Mayor Ebrard of Mexico City, and David Cadman of Vancouver have, respectively, led the C40, World Mayors Council on Climate Change and International Council for Local Environmental Initiatives (ICLEI). 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 Centre to serve as a repository of knowledge, models and data on climate change impacts, vulnerability and risks (Romero-Lankao *et al*., 2013). 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).

The climate plans of the three cities are far reaching, including mitigation and adaptation strategies related to their sustainability goals. The three cities emphasize different priorities in their climate action plans. Mexico City seeks to reduce water and transportation emissions through such actions as improvements in infrastructure and changes in the share of public transport. Vancouver has prioritized the separation of sanitary and stormwater systems, 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 systems to include all essential city infrastructure (Ray *et al*., 2013). Overall, few proposed actions will result in immediate effects, and instead call for additional planning, highlighting the significant effort necessary for comprehensive responses.

Overall, adaptation planning in the three cities faces many challenges. In all three regions, multi-jurisdictional governance structures with differing approaches to climate change challenge the ability for coordinated responses (Solecki, 2012; Romero-Lankao *et al*., 2013). Conflicts in priorities and objectives between various actors and sectors are also prevalent (Burch, 2010). For instance, authorities in Mexico City concerned with avoiding growth into risk-prone and conservation areas (Aguilar and Santos, 2011) compete for regulatory space within a policy agenda that is already coping with a wide range of economic and developmental imperatives (Romero-Lankao *et al.*, 2013).

Climate responses require new types of localized scientific information, such as vulnerability analyses and flood risk assessments, which are not always available (Romero-Lankao *et al.*, 2012a; 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 human settlements. Comprehensive planning is still limited as well. For example, although scholarship exists on disparities in household- and population-level vulnerability and adaptive capacity (Villeneuve and Burnett, 2003; Cutter *et al.*, 2003; Douglas *et al.*, 2012; Romero-Lankao *et al.*, 2013b), equity concerns have received relatively less attention by either of the three cities. Even when local needs are identified, such as the need to protect higher risk homeless and low-income populations (Vancouver), they are often not addressed in action plans.

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26.9. Federal and Subnational Level Adaptation

Along with many local governments (section 26.8.4), federal, and subnational tiers of government across North America are developing climate change adaptation plans. These initiatives, which began at the subnational levels (e.g., (Nunavut Department of Sustainable Development, 2003), appear to be preliminary and relatively little has been done to implement specific measures.

26.9.1. Federal Level Adaptation

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 delegated all federal agencies to 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; 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 creating a Federal Adaptation Policy Framework intended to mainstream climate risks and impacts into programs and activities to help frame government priorities (Environment Canada, 2011a). 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 several adaptation programs and provided new funding to create a Climate Adaptation and Resilience Program for Aboriginals and Northerners, and Enhancing Competitiveness in a Changing Climate program (Environment Canada, 2011b). Canada recently launched an Adaptation Platform to advance adaptation priorities across the country (Natural Resources Canada, 2013).

The US government embarked in 2009 on a 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). A 2013 plan issued by the President enhanced the US government effort supporting adaptation (Executive Office of the President, 2013). The US 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 US 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 US Environmental Protection Agency's Office of Water developed a climate change strategy (U.S. Environmental Protection Agency, National Water Program, 2011).

26.9.2. Subnational Level Adaptation

A number of states and provinces in all three countries have developed adaptation plans. For example, in Canada, Quebec's 2013-2020 adaptation strategy outlines 17 objections covering 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 and livestock loss and community conflict, while protecting aquatic ecosystems (British Columbia Ministry of the Environment, 2010).

In the US 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, 2011; Washington State Human Health and Security Topic Advisory Group, 2011; Washington State Species, Habitats and Ecosystems Topic Advisory Group, 2011; Washington State Natural Resources Working Lands and Waters Topic Advisory Group, 2011).

Of the three national governments, only Mexico requires that states develop adaptation plans. In Mexico, seven of 31 states, 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

Chapter 16 provides a more in-depth discussion on adaptation barriers and limits. Adaptation plans tend to exist as distinct documents and are often not integrated into other planning activities (Preston *et al*., 2011). Most adaptation activities have only involved planning for climate change rather than specific actions, and few measures have been implemented (Preston *et al*., 2011; Bierbaum *et al*., 2012).

Even though Canada and the US are relatively well-endowed in their capacity to adapt, there are significant constraints on adaptation, with financing being a significant constraint in all three countries (Carmin *et al*., 2012). Barriers include legal constraints (e.g., (Jantarasami *et al*., 2010) lack of coordination across different jurisdictions

(Smith *et al*., 2009; National Research Council, 2010; Instituto Nacional de Ecología y Cambio Climático, 2012b), leadership (Smith *et al*., 2009; Moser and Ekstrom, 2010), and divergent perceptions about climate change (Bierbaum *et al*., 2012; Moser, 2013). Although obtaining accurate scientific data was ranked less important by municipalities(Carmin *et al*., 2012), an important constraint is lack of access to scientific information and capacity to manage and use it (Moser and Ekstrom, 2010; Instituto Nacional de Ecología y Cambio Climático, 2012b). Adaptation activities in developed countries such as the US 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). However, making changes to institutions needed to enable or promote adaptations can be costly (Marshall, 2013).

Although multilevel and multisectoral coordination is a key component of effective adaptation, it is constrained by factors such as mismatch between climate and development goals, political rivalry, and lack of national support to regional and local efforts (Brklacich *et al*., 2008; Sander-Regier *et al*., 2009; Brown, 2009; Sydneysmith *et al*., 2010), (Craft and Howlett, 2013; Romero-Lankao *et al*., 2013a). Traditionally, environmental or engineering agencies are responsible for climate issues (e.g., Mexico City, Edmonton and London, Canada), but have neither the decision making power nor the resources to address all dimensions involved. Adaptation planning requires long-term investments by government, business, grassroots organizations and individuals (e.g., Romero-Lankao, 2007; Croci *et al*., 2010; Sarah, 2010; Richardson, 2010).

26.9.4. 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 has high water and energy requirements (Scott *et al*., 2007). Irrigation and air conditioning have immediate adaptive benefits for North American settlements, but are energy-consumptive. Sea walls protect coastal properties, yet negatively affect coastal processes and 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 e.g., peri-urban areas in Mexico (Eakin *et al*., 2010; Romero-Lankao, 2012). 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 synergies and co-benefits. Policies addressing air pollution (Harlan and Ruddell, 2011) or housing for the poor, particularly in Mexico (Colten *et al*., 2008), can often be adapted at low or no cost to fulfill adaptation and sustainability goals (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 regionally or locally-specific vulnerability information (Clark *et al*., 1998; Barsugli *et al*., 2012; Romsdahl *et al*., 2013). Methods for mapping vulnerability have been improved and effectively utilized (Romero-Lankao *et al*., 2013b). Similarly, strategies supporting cultural preservation and subsistence livelihood needs among Indigenous peoples would enhance adaptation (Ford *et al*., 2010b), as would integrating traditional culture with other forms of knowledge, technologies, education and economic development (Hardess *et al*., 2011).

26.10. Key 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 from climate change with an evaluation of the potential for risk reduction through adaptation (Table 26-1). Two of the three examples, wildfires and urban floods, illustrate that multiple climate drivers can result in multiple impacts (e.g., loss of ecosystems integrity, property damage and health impacts due to wildfires and urban floods). The three risks evaluated in Table 26-1 also show that *relative risks* depend on the context specific articulation and dynamics of such factors as

- The magnitude and rate of change of relevant climatic and non-climatic drivers and hazards. For instance, the risk of urban floods depends not only on global climatic conditions (current versus future global mean temperatures of 2˚C and 4˚C), but also on urbanization, a regional source of hazard risk that can enhance or reduce precipitation, as it affects the hydrologic cycle and, hence, has impacts on flood climatology (section 26.8.2.1);
- The internal properties and dynamics of the system being stressed. For example, some ecosystems are more fire-adapted than others. Some populations are more vulnerable to heat-stress because of age, pre-existing medical conditions, working conditions and lifestyles (e.g., outdoor workers, athletes);
- Adaptation potentials and limits. For example, while residential air conditioning (A/C) can effectively reduce health risk, availability and usage of A/C is often limited among the most vulnerable individuals. Furthermore, A/C is sensitive to power failures and its use has mitigation implications.

[INSERT TABLE 26-1 HERE
Table 26-1: Key risks from climate change and the potential for risk reduction through adaptation. Key risks are identified based on assessment of the literature and expert judgments made by authors of this chapter, with supporting evaluation of evidence and agreement in the referenced chapter sections. Each key risk is characterized as very low, low, medium, high, or very high. Risk levels are presented for the near-term era of committed climate change (here, for 2030-2040), in which projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. Risk levels are also presented for the longer-term era of climate options (here, for 2080-2100), for global mean temperature increase of 2°C and 4°C above preindustrial levels. For each timeframe, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state. As the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks. Relevant climate variables are indicated by symbols.]

The judgments about risk conveyed by the Table 26-1 are based on assessment of the literature and expert judgment by chapter authors living under current socio-economic conditions. Therefore, risk levels are estimated for each timeframe, assuming a continuation of current adaptation potentials and constraints. Yet over the course of the 21st century, socioeconomic and physical conditions can change considerably for many sectors, systems and places. The dynamics of wealth generation and distribution, technological innovations, institutions, even culture, can substantially affect North American levels of risk tolerance within the social and ecological systems considered in the Table (see also Box TS.8).

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.*, 2012b) 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 risks 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 impact is climate having on North America? *[to remain at the end of the chapter]*

Recent climate changes and extreme events demonstrate clear impacts of climate-related stresses in North America (*high confidence*). There has been increased occurrence of severe hot weather events over much of the US and increases in heavy precipitation over much of North America (*high confidence*). Such events as droughts in northern Mexico and south-central US, floods in Canada, and hurricanes such as Sandy, demonstrate exposure and vulnerability to extreme climate (*high confidence).* Many urban and rural settlements, agricultural production, water supplies, and human health have been observed to be vulnerable to these and other extreme weather events (Figure 26-2). Forest ecosystems have been stressed through wildfire activity, regional drought, high temperatures, and infestations, while aquatic ecosystems are being affected by higher temperatures and sea level rise.

Many decision makers, particularly in the United States and Canada, have the financial, human and institutional capacity to invest in resilience, yet a trend of rising losses from extremes has been evident across the continent (Figure 26-2), largely due to socio-economic factors, including a growing population, equity issues and increased property value in areas of high exposure. In addition, climate change is *very likely* to lead to more frequent extreme heat events and daily precipitation extremes over most areas of North America, more frequent low snow years, and shifts towards earlier snowmelt runoff over much of the western US and Canada (*high confidence*). These changes combined with higher sea levels and associated storm surges, more intense droughts, and increased precipitation variability are projected to lead to increased stresses to water, agriculture, economic activities and urban and rural settlements (*high confidence*).

FAQ 26.2: Can adaptation reduce the adverse impacts of climate in North America?
[to remain at the end of the chapter]

Adaptation – including land use planning, investments in infrastructure, emergency management, health programs, and water conservation – has significant capacity to reduce risks from current climate and climate change (Figure 26-3). There is increasing attention to adaptation among planners at all levels of government but particularly at the municipal level, with many jurisdictions engaging in assessment and planning processes. Yet, there are few documented examples of implementation of proactive adaptation and these are largely found in sectors with longer-term decision-making, including energy and public infrastructure *(high confidence*). Adaptation efforts have revealed the significant challenges and sources of resistance facing planners at both the planning and implementation stages, particularly the adequacy of informational, institutional, financial and human resources, and lack of political will (*medium confidence*).

While there is high capacity to adapt to climate change across much of North America, there are regional and sectoral disparities in economic resources, governance capacity, and access to and ability to utilize information on climate change which limit adaptive capacity in many regions and among many populations such as the poor and indigenous communities. For example, there is limited capacity for many species to adapt to climate change, even with human intervention. At lower levels of temperature rise, adaptation has high potential to off-set projected declines in yields for many crops, but this effectiveness is expected to be much lower at higher temperatures. The risk that climate stresses will cause profound impacts on ecosystems and society – including the possibility of species extinction or severe adverse socio-economic shocks – highlights limits to adaptation.

References

Abramson, D.M. and I.E. Redlener, 2013: Hurricane Sandy: lessons learned, again. *Disaster Medicine and Public Health Preparedness,* **6(4)**, 328-329.
Acclimatise, 2009: *Building business resilience to inevitable climate change*. In: Carbon project disclosure report 2008. FTSE 350, Oxford.
Aguilar, A.G. and C. Santos, 2011: Informal settlements' needs and environmental conservation in Mexico City: An unsolved challenge for land-use policy. *Land use Policy,* **28(4)**, 649-662.
Aguilera, E., L. Lassaletta, A. Gattinger, and B.S. Gimeno, 2013: Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agriculture, Ecosystems & Environment,* **168**, 25-36.
Ahmed, S.A., N.D. Diffenbaugh, and T. Hertel, 2009: Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters,* **4(3)**, 034004.
Akbari, H., S. Menon, and A. Rosenfeld, 2009: Global cooling: increasing world-wide urban albedos to offset CO 2. *Climatic Change,* **94(3)**, 275-286.
Alam, M.M., C. Siwar, R.I. Molla, B. Talib, and M.E.B. Toriman, 2012: Paddy farmers' adaptation practices to climatic vulnerabilities in Malaysia. *Mitigation and Adaptation Strategies for Global Change,* **17**, 415-423.
Alexander et al., 2006: Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research,* **111(D5)**, D05109.
Alig, R.J., J.D. Kline, and M. Lichtenstein, 2004: Urbanization on the US landscape: looking ahead in the 21st century. *Landscape and Urban Planning,* **69(2)**, 219-234.
Allen, C.D., A. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, P. Gonzales, T. Hogg, A. Rigling, and D.D. Breshears, 2010: A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management,* **259(4)**, 660-684.
Almaraz, J.J., F. Mabood, X. Zhou, E.G. Gregorich, and D.L. Smith, 2008: Climate change, weather variability and corn yield at a higher latitude locale: Southwestern Quebec. *Climatic Change,* **88(2)**, 187-197.
American Society of Civil Engineers, 2009: *2009 Report Card for America's Infrastructure*. American Society of Civil Engineers, Reston, Virginia.
Anderegg, W.R.L., J.A. Berry, D.D. Smith, J.S. Sperry, L.D.L. Anderegg, and C.B. Field, 2012: The roles of hydraulic and carbon stress in a widespread climate-induced forest die-off. *Proceedings of the National Academy of Sciences,* **109(1)**, 233-237.
Anderegg, W.R.L., J.M. Kane, and L.D.L. Anderegg, 2013: Consequences of widespread tree mortality triggered by drought and temperature stress. *Nature Climate Change,* **3**, 30-36.
Anderson, B.J., H.R. Akcakaya, M.B. Araujo, D.A. Fordham, E. Martinez-Meyer, W. Thuiller, and B.W. Brook, 2009: Dynamics of range margins for metapopulations under climate change. *Proceedings of the National Academies of Science,* **276(1661)**, 1415-1420.
Anderson, B.G. and M.L. Bell, 2009: Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology,* **20(2)**, 205.
Anderson, C. and S. McLachlan, 2012: Exiting, enduring and innovating: Farm household adaptation to global zoonotic disease. *Global Environmental Change,* **22**, 82-93.
Anderson, R.G., J.G. Canadell, J.T. Randerson, R.B. Jackson, B.A. Hungate, D.D. Baldocchi, G.A. Ban-Weiss, G.B. Bonan, K. Caldeira, L. Cao, N.S. Diffenbaugh, K.R. Gurney, L.M. Kueppers, B.E. Law, and S. Luyssaert and T.L. O'Halloran, 2011: Biophysical considerations in forestry for climate protection. *Frontiers in Ecology and the Environment,* **9**, 174-182.

Anderson, M., S. Dobardzic, and D. Gardiner, 2006: *Climate change and insurance: An agenda for action in the United States*. Allianz Group and WWF, Munchen, Germany and Washington, D.C.
Andrachuk, M. and T. Pearce, 2010: Vulnerability and adaptation in two communities in the Inuvialuit settlement region. In: *Community Adaptation and Vulnerability in Arctic Regions*. [Hovelsrud, G.K. and B. Smit(eds.)]. Springer, New York, pp. 63-81.
Anguelovski, I. and J.A. Carmin, 2011: Something borrowed, everything new: innovation and institutionalization in urban climate governance. *Current Opinion in Environmental Sustainability,* **3(3)**, 169-175.
Arbuckle Jr, J.G., L.S. Prokopy, T. Haigh, J. Hobbs, T. Knoot, C. Knutson, A. Loy, A.S. Mase, J. McGuire, L.W. Morton, J. Tyndall, and M. Widhalm, 2013: Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. *Climate Change,* **117**, 943-950.
Ariano, R., G.W. Canonica, and G. Passalacqua, 2010: Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Annals of Allergy, Asthma & Immunology,* **104(3)**, 215-22.
Asseng, S., F. Ewert, C. Rosenzweig, J.W. Jones, J.L. Hatfield, A.C. Ruane, K.J. Boote, P.J. Thorburn, R.P. Rotter, D. Cammaranol, N. Brisson, B. Basso, P. Martre, P.K. Aggarwal, C. Angulo, P. Bertuzzi, C. Biernath, A.J. Challinor, J. Doltra, S. Gayler, R. Goldberg, R. Grant, L.N. Kumar, C. Nendel, G. O'Leary, J.E. Olesen, T.M. Osborne, T. Palosuo, E. Priesack, D. Ripoche, M.A. Semenov, I. Shcherbak, P. Steduto, C. Stockle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, M. Travasso, K. Waha, D. Wallach, J.W. White, J.R. Williams, and J. Wolf, 2013: Uncertainty in simulating wheat yields under climate change. *Nature Climate Change,* .
Auffhammer, M. and A. Aroonruengsawat, 2011: Simulating the impacts of climate change, prices and population on California's residential electricity consumption. *Climatic Change,* **109**, S191-S210.
Auffhammer, M. and A. Aroonruengsawat, 2012: Erratum to: Simulating the impacts of climate change, prices and population on California's residential electricity consumption. *Climatic Change,* **113**, 1101-1104.
Auld, H., J. Waller, S. Eng, J. Klaasen, R. Morris, S. Fernandez, V. Cheng, and D. MacIver, 2010: The Changing Climate and National Building Codes and Standards.Proceedings of American Meteorological Society, Ninth Symposium on the Urban Environment, Session 5.6, August 1-6, 2010, Keystone, CO, US, .
Autor, D.H., L.F. Katz, and M.S. Kearney, 2008: Trends in U.S. wage inequality: Revising the revisionists. *The Review of Economics and Statistics,* **90(2)**, 300-323.
Autorite des Marches Financiers, 2011: *Managing Climate Change Risk: Findings of 2010 survey of property and casualty insurers operating in Quebec*. AMF.
Averyt, K., J. Fisher, A. Huber-Lee, A. Lewis, N. Macknick, J. Madden, S. Rogers, and S. Tellinghuisen, 2011: *Freshwater Use by US Power Plants, Union of Concerned Scientists, Cambridge MA.*
Avise, J., J. Chen, B. Lamb, C. Wiedinmyer, A. Guenther, and E. Salath, 2009: Attribution of projected changes in summertime US ozone and PM 2.5 concentrations to global changes. *Atmospheric Chemistry and Physics,* **9**, 1111-1124.
AXA Ipsos, 2012: *Individual perceptions of climate change risk*. [AXA Ipsos (ed.)], pp. 1-18.
Axelson, J.N., D.J. Sauchyn, and J. Barichivich, 2012: New reconstructions of streamflow variability in the South Saskatchewan River Basin from a network of tree ring chronologies, Alberta, Canada. *Water Resources Research,* **45(9)**.
Azumaya, T., T. Nagasawa, O.S. Temnykh, and G.V. Khen, 2007: Regional and seasonal differences in temperature and salinity limitations of pacific salmon. *North Pacific Anadromous Fish Commission,* **4**, 179-187.
Baade, R.A., R. Baumann, and V. Matheson, 2007: Estimating the economic impact of natural and social disasters, with an application to Hurricane Katrina. *Urban Studies,* **44(11)**, 2061-2076.
Backus, G.A., T.S. Lowry, and D.E. Warren, 2013: The near-term risk of climate uncertainty among the U.S. states. *Climatic Change,* **116(3-4)**, 495-522.
Badjek, M., E.H. Allison, A.S. Halls, and N.K. Dulvy, 2010: Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy,* **34**, 375-383.
Balshi, M.S., A.D. McGuirez, P. Duffy, M. Flannigan, J. Walsh, and J. Melillo, 2009: Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology,* **15**, 578-600.
Barnett, T.P., J.C. Adam, and D.P. Lettenmaier, 2005: Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature,* **438(7066)**, 303-309.
Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A. Wood, T. Nozawa, A. Mirin, D. Cavan, and M.D. Dettinger, 2008: Human-induced changes in the hydrology of the western United States. *Science,* **319(5866)**, 1080-1083.

Barragan, A.R., L. Bourillon, S. Calme, N. Castelblanco, P. Charruau, J.J. Dominguez Calderon, C. Espadas Manrique, J.M. Espinoza Rodriguez, M. Garcia Rivas, M. Salgado, C. Sotelo, A. Perdomo, W. Hadad, H.H. Arena, V. Hernandez, Y. Gomez, R. Landa, D. Lugo, B. Morales, G. Martinez, O. Moreno, A. Rhodes, Y. Romero, C. Pigueron, C. Pozo, V. Hernandez, I. Salazar, F. Secaira, N. Simones, F. Guerrero, N. Valle, M. Hernandez, and R. Gutierrez, 2011: *Adaptación al Cambio Climático en Áreas Protegidas del Caribe de México
*. In: Serie Estrategias de Adaptación al Cambio Climático en Áreas Protegidas de México [March, I.J., Cabral, H., Echeverría, Y., Bellot, M. and Frausto, J.M. (eds.)]. Comisión Nacional de Áreas Naturales Protegidas, The Nature Conservancy, Fondo Mexicano para la Conservación de la Naturaleza, México, pp. 1-109.

Barsugli, J.J., J.M. Vogel, L. Kaatz, J.B. JSmith, M. Waage, and C. Anderson, 2012: Two faces of uncertainty: Climate science and water utility planning methods. *Journal of Water Resources Planning and Management,* **138(5)**, 389-395.

Barthel, F. and E. Neumayer, 2012: A trend analysis of normalized insured damage from natural disasters. *Climatic Change,* **113**, 215-237.

Battin, J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007: Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy Sciences,* **104(16)**, 6720-6725.

Battisti, D.S. and R.L. Naylor, 2009: Historical warnings of future food insecurity with unprecedented seasonal heat. *Science,* **323(5911)**, 240-244.

Baumgart-Getz, A., L. Prokopy, and K. Floress, 2012: Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of Environmental Management,* **96(1)**, 17-25.

Bee, B., M. Biermann, and P. Tschakert, 2013: Gender, development, and rights-based approaches: Lessons for climate change adaptation and adaptive social protection. *Research, Action and Policy: Addressing the Gendered Impacts of Climate Change,* , 95-108.

Beebe, N.W., R.D. Cooper, P. Mottram, and A.W. Sweeney, 2009: Australia's dengue risk driven by human adaptation to climate change. *PLoS Neglected Tropical Diseases,* **3(5)**, e429.

Beef Today Editors, 2013: Cargill to idle Texas beef processing plant. *AgWeb Farm Journal,* **January 17**.

Belanger, D., P. Berry, V. Bouchet, D. Charron, K. Clarke, B. Doyon, M. Fleury, C. Furgal, P. Gosselin, S. Lamy, L.R. Lindsay, G. McBean, N.H. Ogden, J. Seguin, C.J. Shuster, and C.L. Soskolne, 2008a: *Human Health in a Changing Climate : A Canadian Assessment of Vulnerabilities and Adaptive Capacity*. Health Canada, Ottowa, Ontario, .

Belanger, D., B. Peter, V. Bouchet, D. Charron, K. Clarke, B. Doyon, M. Fleury, C. Furgal, P. Gosselin, S. Lamy, L.R. Lindsay, G. McBean, N.H. Ogden, J. Segun, C.J. Shuster, and C.L. Soskolne, 2008b: *Human Health in a Changing Climate: A Canadian assessment of Vulnerabilities and Adaptive Capacity*. [Segun, J. (ed.)]. Health Canada, Ottawa, ON, pp. 1-484.

Bell, M.L., R. Goldberg, C. Hogrefe, P.L. Kinney, K. Knowlton, B. Lynn, J. Rosenthal, C. Rosenzweig, and J.A. Patz, 2007: Climate change, ambient ozone, and health in 50 US cities. *Climatic Change,* **82(1)**, 61-76.

Bender, M.A., T.R. Knutson, R.E. Tuleya, J.J. Sirutis, G.A. Vecchi, S.T. Garner, and I.M. Held, 2010: Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science,* **327(5964)**, 454-458.

Bentz, B.J., J. Régnière, C.F. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negrón, and S.J. Seybold, 2010: Climate change and bark beetles of the Western United States and Canada: Direct and Indirect Effects. *Bioscience,* **60(8)**, 602-613.

Berry, H.L., K. Bowen, and T. Kjellstrom, 2010: Climate change and mental health: a causal pathways framework. *International Journal of Public Health,* **55(2)**, 123-32.

Bethel, J.W., A.N. Foreman, and S.C. Burke, 2011: Disaster preparedness among medically vulnerable populations. *American Journal of Preventive Medicine,* **40(2)**, 139-143.

Bhatti, J.S., M.J. Apps, and R. Lal, 2006: Anthropogenic changes and the global carbo cycle. In: *Climate change and managed ecosystems*. [Bhatti, J.S., M.J. Apps, R. Lal, and M.A. Price(eds.)]. Taylor & Francis, Boca Raton, FL, pp. 71-91.

Bierbaum, R., J.B. Smith, A. Lee, M. Blair, F.S.I. Chapin, P. Fleming, S. Russo, M. Stults, S. McNeely, E. Wasley, and L. Verduzco, 2012: A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change,* **18(3)**, 361-401.

Bin, O., C. Dumas, B. Poulter, and J. Whitehead, 2007: *Measuring the impacts of climate change on North Carolina coastal resources*. East Carolina University, Greenville, NC, pp. 101.

Bjarndadottir, S., Y. Li, and M.G. Stewart, 2011: A probabilistic-based framework for impact and adaptation assessment of climate change on hurricane damage risks and costs. *Structural Safety,* **33**, 173-185.

Black, R., N.W. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D.S.G. Thomas, 2011: The effect of environmental change on human migration. *Global Environmental Change,* **215**, S3-S11.

Blake, E.S., C.W. Landsea, and E.J. Gibney, 2007: *The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2006 (and other frequently requested hurricane facts).* NOAA/National Weather Service, National Centers for Environmental Prediction, National Hurricane Center, .

Blake, R., A. Grimm, T. Ichinose, R. Horton, S. Gaffin, S. Jiong, D. Bader, and D. Cecil, 2011: Urban Climate Processes, trends and projections. In: *Climate change and cities: first assessment report of the Urban Climate Change Research Network.* [Rosenzweig, C., W.D. Solecki, and S.A. Hammer(eds.)]. Cambridge University Press, New York, NY, pp. 43-83.

Bloomberg, M., 2012: Remarks delivered at the New York Marriott Downtown.December 6, 2012, .

Bond, W.J. and J.E. Keeley, 2005: Fire as a global "herbivore": the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution,* **20**, 387-394.

Bond, W. and B. Van Wilgen, 1996: Fire and Plants (Population and Community Biology Series 14).

Bonsal, B.R., R. Aider, P. Gachon, and S. Lapp, 2012: An assessment of Canadian prairie drought: Past, present, and future. *Climate Dynamics,* **41(2)**, 501-516.

Bootsma, A., S. Gameda, and D.W. McKenney, 2005: Potential impacts of climate change on corn, soybeans and barley yields in Atlantic Canada. *Canadian Journal of Soil Science,* **85**, 345-357.

Bornehag, C.G., G. Blomquist, F. Gyntelberg, B. Jarvholm, P. Malmberg, L. Nordvall, A. Nielsen, G. Pershagen, and J. Sundell, 2001: Dampness in buildings and health. *Indoor Air,* **11(2)**, 72-86.

Boruff, B.J., C. Emrich, and S.L. Cutter, 2005: Erosion hazard vulnerability of US coastal counties. *Journal of Coastal Research,* , 932-942.

Brenkert-Smith, H., 2010: Building bridges to fight fire: The role of informal social interactions in six Colorado wildland-urban interface communities. *International Journal of Wildland Fire,* **19**, 689-697.

Bresch, D. and A. Spiegel, 2011: *A blueprint for managing climate risks in emerging markets.* Swiss Re.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005: Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences,* **102(42)**, 15144-15148.

Bright, E.A., P.R. Coleman, A.N. Rose, and M.L. Urban, 2012: *Landscan 2011* Oakridge National Laboratory, Oakridge, TN.

British Columbia Ministry of the Environment, 2010: *Preparing for Climate Change: British Columbia's Adaptation Strategy.* British Columbia Ministry of the Environment, Victoria, British Columbia.

Brklacich, M., M. Woodrow, R. McLeman, and K. Vodden, 2008: *Enhancing the Capacity of Canadian Rural Communities to Adapt to Uncertain Futures.* In: Project No. A1397, June 30. Canadian Climate Impacts and Adaptation Program, Ottawa: Natural Resources Canada.

Brooks, S. and M. Loevinsohn, 2011: Shaping agricultural innovation systems responsive to food insecurity and climate change. *Natural Resources Forum,* **35**, 185-200.

Brown, P.J., R.S. Bradley, and F.T. Keimig, 2010: Changes in Extreme Climate Indices for the Northeastern United States, 1870-2005. *Journal of Climate,* **23**, 6555-6572.

Brown, H.C.P., 2009: Climate change and Ontario forests: Prospects for building institutional adaptive capacity. *Mitigation and Adaptation Strategies for Global Change,* **14**, 513.

Browne, M.J. and R.E. Hoyt, 2000: The demand for flood insurance: empirical evidence. *Journal of Risk and Uncertainty,* **20(3)**, 291-306.

Bryant, C., B. Singh, and P. Thomassin, 2008: *Evaluation of agricultural adaptation processes and adaptive capacity to climate change and variability: The co-construction of new adaptation planning tools with stakeholders and farming communities in the Saguenay-Lac-Saint-Jean and Monteregie regions of Quebec.* Natural Resources Canada Climate Change Impacts and Adaptation Program.

Buechler, S., 2009: Gender, water, and climate change in Sonora, Mexico: implications for policies and programmes on agricultural income-generation. *Gender & Development,* **17**, 51-66.

Burch, S., 2010: Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada. *Global Environmental Change,* **20(2)**, 287-297.

Bureau of Reclamation, 2007: *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* U.S. Department of the Interior, .

Bureau of Reclamation, 2013: *Colorado River Basin Water Supply and Demand Study* U.S. Department of the Interior, .

Butler, E.E. and P. Huybers, 2012: Adaptation of US maize to temperature variations. *Nature Climate Change,* **3(1)**, 68-72.

Buttle, J., J.T. Muir, and J. Frain, 2004: Economic impacts of climate change on the Canadian Great Lakes hydro-electric power producers: A supply analysis. *Canadian Water Resources Journal,* **29**, 89-109.

Cabas, J., A. Weersink, and E. Olale, 2010: Crop yield response to economic, site and climate variables. *Climatic Change,* **101**, 599-616.

Cai, X., D. Wang, and R. Laurent, 2009: Impact of Climate Change on Crop Yield: A Case Study of Rainfed Corn in Central Illinois. *Journal of Applied Meteorology & Climatology,* **48**, 1868-1881.

Cakmak, S., R.E. Dales, R.T. Burnett, S. Judek, F. Coates, and J.R. Brook, 2002: Effect of airborne allergens on emergency visits by children for conjunctivitis and rhinitis. *Lancet,* **359(9310)**, 947-8.

California Department of Water Resources, 2009: *Bulletin 160-09 California Water Plan Update 2009*. State of California, Sacramento, CA.

California Natural Resources Agency, 2009: *2009 California Climate Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008*. State of California, Sacramento, CA.

Campos, M., D. Herrador, C. Manuel, and M.K. McCall, 2013: Adaptation strategies to climate change in two rural communities in Mexico and El Salvador. *Boletín De La Asociación De Geógrafos Españoles,* **61**, 433-436.

Canadian Council of Professional Engineers, 2008: *Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure*.

Carmin, J., N. Nadkarni, and C. Rhie, 2012: *Progress and Challenges in Urban Climate Adaptation Planning: Results of a Global Survey*. Massachusetts Institute of Technology, Cambridge, MA.

Carriere, A., M. Prevost, A. Zanyadi, P. Chevalier, and B. Barbeau, 2010: Vulnerability of Quebec drinking water treatment plants to cyanotoxins in a climate change context. *Journal of Water and Health,* **8(3)**, 455-465.

Carroll, M.S., P.J. Cohn, T.B. Paveglio, D.R. Drader, and P.J. Jakes, 2010: Fire burners to firefighters: the Nez Perce and fire. *Journal of Forestry,* **108(2)**, 71-76.

Cayan, D.R., K.T. Redmond, and L.G. Riddle, 1999: ENSO and hydrologic extremes in the Western United States. *Journal of Climate,* **12**, 2881-2893.

Cayan, D.R., T. Das, D.W. Pierce, T.P. Barnett, M. Tyree, and A. Gershunov, 2010: Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proceedings of the National Academy of Sciences,* **107(50)**, 21271-21276.

CBS Chicago, 2012: *City Sets July 5 Record At 103°; Heat Blamed For 2 Deaths* CBS News, Chicago Illinois, .

Center for Disease Control and Prevention, 2011: Surveillance for Waterborne Disease Outbreaks and Other Health Events Associated with Recreational Water — United States, 2007–2008 and Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water — United States, 2007–2008. *Morbidity and Mortality Weekly Report,* **60(12)**, 1-80.

Centre d'expertise hydrique du Québec, 2003: *Measures Provided by the Dam Safety Act and Regulation*. Government of Quebec, Quebec, Canada.

Centre for Research on the Epidemeology of Disasters, 2012: *EM-DAT: The International Disaster Data Base* Centre for Research on the Epidemeology of Disasters;, Brussels, Belgium, .

Chambers, J.Q., J.I. Fisher, H. Zeng, E.L. Chapman, D.B. Baker, and G.C. Hurtt, 2007: Hurricane Katrina's Carbon Footprint on U.S. Gulf Coast Forests. *Science,* **318(5853)**, 1107-1107.

Chang, W., V.A. Lantz, and D.A. MacLean, 2009: Public attitudes about forest pest outbreaks and control: Case studies in two Canadian provinces. *Forest Ecology and Management,* **257(4)**, 1333-1343.

Chang, H.H., J. Zhou, and M. Fuentes, 2010: Impact of climate change on ambient ozone level and mortality in southeastern United States. *Int. J. Environ. Res. Public Health,* **7**, 2866-2880.

Chen, C.C. and B.A. McCarl, 2009: Hurricanes and possible intensity increases: effects on and reactions from U.S. agriculture. *Journal of Agricultural and Applied Economics,* **41**, 125-144.

Chen, F., S. Miao, M. Tewari, J.W. Bao, and H. Kusaka, 2011a: A numerical study of interactions between surface forcing and sea breeze circulations and their effects on stagnation in the greater Houston area. *Journal of Geophysical Research: Atmospheres (1984-2012),* **116**, D12105.

Chen, J., W. Xu, J. Velten, Z. Xin, and J. Stout, 2012: Characterization of maize inbred lines for drought and heat tolerance. *Journal of Soil and Water Conservation,* **67(5)**, 354-364.

Chen, J., F.P. Brissette, and R. Leconte, 2011b: Uncertainty of downscaling method in quantifying the impact of climate change on hydrology. *Journal of Hydrology,* **401(3)**, 190-202.

Chen, J., J. Avise, B. Lamb, and E. Salath, 2009: The effects of global changes upon regional ozone pollution in the United States. *Atmospheric Chemistry and Physics,* **9**, 1125-1141.

Chhetri, N.B., W.E. Easterling, E. Terandoc, and L. Mearns, 2010: Modeling Path Dependence in Agricultural Adaptation to Climate Variability and Change. *Annals of the Association of American Geographers,* **100(4)**, 894-907.

Chiffoleau, Y., 2009: From Politics to Co-operation: The Dynamics of Embeddedness in Alternative Food Supply Chains. *Sociologia Ruralis,* **49(3)**, 218-235.

Chinowsky, P., J.C. Price, and J. Neumann, 2013: Assessment of Climate Change Adaptation Costs for the U.S. Road Network. *Global Environmental Change,* **23**, 764-773.

Chiotti, Q. and B. Lavender, 2008: Ontario. In: *From Impacts to Adaptation: Canada in a Changing Climate*. [Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush(eds.)]. Government of Canada, Ottawa, pp. 227-274.

Choi, W., P.F. Rasmussen, A.R. Moore, and S.J. Kim, 2009: Simulating streamflow response to climate scenarios in central Canada using a simple statistical downscaling method. *Climate Research,* **40(1)**, 89-102.

Chouinard, O., S. Plante, and G. Martin, 2008: The community engagement process: A governance approach in adaptation to coastal erosion and flooding in Atlantic Canada. *Canadian Journal of Regional Science,* **31(3)**, 507-520.

Christianson, A., T.K. McGee, and L. L'Hirondelle, 2012a: Community support for wildfire mitigation at Peavine Métis Settlement, Alberta, Canada. *Environmental Hazards,* **11(3)**, 177-193.

Christianson, A., T.K. McGee, and L. L'Hirondelle, 2012b: How historic and current wildfire experiences in an Aboriginal community influence mitigation preferences. *International Journal of Wildland Fire,* .

City of Vancouver, 2012: *Climate Change Adaptation Strategy*. City of Vancouver, Vancouver, Canada.

Clark, G.E., S.C. Moser, S.J. Ratick, K. Dow, W.B. Meyer, S. Emani, W. Jin, J.X. Kasperson, R.E. Kasperson, and H.E. Schwarz, 1998: Assessing the vulnerability of coastal communities to extreme storms: The case of Revere, MA., USA. *Mitigation and Adaptation Strategies for Global Change,* **3**, 59-82.

Clot, B., 2003: Trends in airborne pollen: an overview of 21 years of data in Neuchâtel (Switzerland). *Aerobiologia,* **19(3)**, 227-234.

Coffee, J.E., J. Parzen, M. Wagstaff, and R.S. Lewis, 2010: Preparing for a changing climate: The Chicago climate action plan's adaptation strategy. *Journal of Great Lakes Research,* **36**, 115-117.

Coleman, J.M.A., F.S. Sosa-Rodriguez, L. Mortsch, and P. Deadman, 2013: Assessing Stakeholder Impacts and Adaptation to Low-water Levels: The Trent-Severn Waterway (in review). *Climatic Change,* .

Coles, A.R. and C.A. Scott, 2009: Vulnerability and adaptation to climate change and variability in semi-arid rural southeastern Arizona, USA. *Natural Resources Forum,* **33(4)**, 297-309.

Collins, M.J., 2009: Evidence for changing flood risk in New England since the late 20th century. *Journal of the American Water Resources Association,* **45(2)**, 279-290.

Collins, T.W., 2008: The political ecology of hazard vulnerability: marginalization, facilitation and the production of differential risk to urban wildfires in Arizona's White Mountains. *Journal of Political Ecology,* **15**, 21-43.

Collins, T.W. and B. Bolin, 2009: Situating hazard vulnerability: people's negotiations with wildfire environments in the US Southwest. *Environmental Management,* **44(3)**, 441-455.

Collins, T.W., S.E. Grineski, J. Chakraborty, and Y.J. McDonald, 2011: Understanding environmental health inequalities through comparative intracategorical analysis: Racial/ethnic disparities in cancer risks from air toxics in El Paso County, Texas. *Health & Place,* **17(1)**, 335-344.

Colten, C., R. Kates, and S. Laska, 2008: *Community Resilience: Lessons from New Orleans and Hurricane Katrina*. In: CAPRI Report 3. Oak Ridge National Laboratory, Oak Ridge, TN.

Comfort, L.K., 2006: Cities at Risk. *Urban Affairs Review,* **41(4)**, 501.

Comisión Económica para América Latina y el Caribe, *CEPAL Statistic Databases: Population, By Age Group, by sex* Comisión Económica para América Latina y el Caribe, Vitacura, Santiago de Chile.

Comisión Intersecretarial de Cambio Climatico, 2009: *Programa Especial de Cambio Climatico 2008-2012*. Secretaria de Medio Ambiente y Recursos Naturales, Mexico.

Comisión Nacional de Áreas Naturales Protegidas and The Nature Conservancy, Programa México, 2009: *Programa de manejo integral del fuego, Reserva de la Biosfera Selva El Ocote Chiapas, México 2009-2012*.Mexico, D.F., .

Comisión Nacional del Agua, 2011: *Atlas del Agua en México*. Secretaria de Medio Ambiente y Recursos Naturales, México, D.F.

Comisión Nacional Forestal, 2012a: Proceedings of Seminario de información estadística y geográfica para prevenir y mitigar los efectos de la sequía e inundaciones en la población y la economía, November 14-15, 2011, Mexico, D.F., .

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Naturales Protegidas, The Nature Conservancy, Programa México, and Pronatura, 2007: *Análisis de vacíos y omisiones en conservación de la biodiversidad marina de México: océanos, costas e islas*. Comisión Nacional para el conocimiento y Uso de la Biodiversidad; Comisión Nacional de Áreas Naturales Protegidas; The Nature Conservancy-Programa México; Pronatura A.C., México, D.F.

Committee on Flood Control Alternatives in the American River Basin, Environment and Resources Commission on Geosciences, and Division on Earth and Life Studies and National Research Council, 1995: *Flood Risk Management and the American River Basin: An Evaluation*. The National Academies Press, Washington, D.C., .

Conde, C., R. Ferrer, and S. Orozco, 2006: Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. *Atmosfera,* **19(3)**, 181-194.

Conrad, E., 2010: *Climate Change and Infrastructure in the Gulf of Mexico and Caribbean Basin: New Risks to Building Blocks of Resilience*. In: Fighting for Survival: The Vulnerability of America's Gulf Coast and the Caribbean Basin. Tulane University, New Orleans, Louisiana, pp. 63-88.

Cooper, D.C. and G. Sehlke, 2012: Sustainability and Energy Development: Influences of Greenhouse Gas Emission Reduction Options on Water Use in Energy Production. *Environmental Science & Technology,* **46(6)**, 3509-3518.

Cooper, M.J.P., M.D. Beevers, and M. Oppenheimer, 2008: The potential impacts of sea level rise on the coastal region of New Jersey, USA. *Climatic Change,* **90**, 475-492.

Costello, C.J., O. Deschênes, and C.D. Kolstad, 2009: *Economic Impacts of Climate Change on California Agriculture
*. California Energy Commission, Santa Barbara, CA.

Craft, J. and M. Howlett, 2013: Policy Capacity and the Ability to Adapt to Climate Change: Canadian and US Case Studies. *Review of Policy Research,* **30(1)**, 1-18.

Craine, J.M., A.J. Elmore, K.C. Olson, and D. Tollesons, 2010: Climate change and cattle nutritional stress. *Global Change Biology,* **16**, 2901-2911.

Crawford, W., D. Johannessen, F. Whitney, R. Birch, K. Borg, D. Fissel, and S. Vagle, 2007: *Appendix C: Physical and Chemical Oceanography in B. G. Lucas, S. Verrin, and R. Brown, editors. In: Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA)*. In: Canadian Technical Report of Fisheries and Aquatic Sciences 2667 [Lucas, B.G., Verrin, S. and Brown, R. (eds.)]. Institute of Ocean Sciences, Sidney, British Columbia.

Croci, E., S. Melandri, and T. Molteni, 2010: *A Comparative Analysis of Global City Policies in Climate Change Mitigation: London, New York, Milan, Mexico City and Bangkok*. In: IEFE Working Paper No. 32. IEFE Bocconi University Working Paper.

Cross, M.S., E.S. Zavaleta, D. Bachelet, M.L. Brooks, C.A.F. Enquist, E. Fleishman, L. Graumlich, C.R. Groves, L. Hannah, L. Hansen, G. Hayward, M. Koopman, J. Lawler, J.R. Malcolm, J. Nordgren, B. Petersen, E.L. Rowland, D. Scott, S.L. Shafer, M.R. Shaw, and G.M. Tabor, 2012: The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. *Environmental Management,* **50(3)**, 341-351.

Cross, M.S., P.D. McCarthy, G. Garfin, D. Gori, and C.A. Enquist, 2013: Accelerating adaptation of natural resource management to address climate change. *Conservation Biology,* **27(1)**, 4-13.

Crozier, L.G., R.W. Zabel, and A. Hamlet, 2008: Predicting differential effects of climate change at the population level with life-cycle models of spring Chinook salmon. *Global Change Biology,* **14(2)**, 236-249.

Cueva-Luna, T.E., R. Few, and A. Mercado, 2011: Afrontando el cambio climático y los riesgos contra la salud: respuestas en la Sierra Tarahumara [Coping with climate change and health risks: responses in the Sierra Tarahumara]. *Estudios Demográficos Y Urbanos,* **26(3)**, 671-708.

Cuo, L., D.P. Lettenmaier, M. Alberti, and J.E. Richey, 2009: Effects of a century of land cover and climate change on the hydrology of the Puget Sound basin. *Hydrological Processes,* **23(6)**, 907-933.

Curriero, F.C., J.a. Patz, J.B. Rose, and S. Lele, 2001: The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American Journal of Public Health,* **91(8)**, 1194-9.
Cutter, S., B. Solecki, N. Bragado, J. Carmin, M. Fragkias, M. Ruth, and T. Wilbanks, 2013: Chapter 11 – Urban Systems, Infrastructure, and Vulnerability. In: *Federal Advisory Committee Draft Climate Assessment*. National Climate Assessment and Development Advisory Committee, Washington, D.C., .
Cutter, S.L. and C. Emrich, 2005: Are natural hazards and disaster losses in the US increasing? *EOS, Transactions American Geophysical Union,* **86(41)**, 381.
Cutter, S.L., B.J. Boruff, and W.L. Shirley, 2003: Social Vulnerability to Environmental Hazards*. *Social Science Quarterly,* **84(2)**, 242-261.
Cutter, S.L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb, 2008: A place-based model for understanding community resilience to natural disasters. *Global Environmental Change,* **18(4)**, 598-606.
Dai, A.G., 2011: Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change,* **2**, 45-65.
Daley, M.L., J.D. Potter, and W.H. McDowell, 2009: Salinization of urbanizing New Hampshire streams and groundwater: Effects of road salt and hydrologic variability. *Journal of the North American Benthological Society,* **28(4)**, 929-940.
Das, T., M.D. Dettinger, D.R. Cayan, and H.G. Hidalgo, 2011: Potential increase in floods in California's Sierra Nevada under future climate projections. *Climatic Change,* **109(1)**, 71-94.
Davis, J.B., 2004: Healthy Forests Initiatige: Unhealthy Policy Choices in Forest and Fire Management, The. *Envtl.L.,* **34**, 1209.
Daw, T., W.N. Adger, K. Brown, and M.C. Badjeck, 2009: *Climate change and capture fisheries: potential impacts, adaptation and mitigation*. In: *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*.FAO Fisheries and Aquaculture Technical Paper, No. 530 [Cochrane, K., De Young, C., Soto, D. and Bahri, T. (eds.)]. FAO, Rome, Italy, pp. 7-106.
DeGaetano, A.T., 2009: Time-Dependent Changes in Extreme-Precipitation Return-Period Amounts in the Continental United States. *Journal of Applied Meteorology and Climatology,* **48(10)**, 2086-2099.
Degallier, N., C. Favier, C. Menkes, M. Lengaigne, W.M. Ramalho, R. Souza, J. Servain, and J.P. Boulanger, 2010: Toward an early warning system for dengue prevention: modeling climate impact on dengue transmission. *Climatic Change,* **98(3)**, 581-592.
Delfino, R.J., 2002: Epidemiologic evidence for asthma and exposure to air toxics: linkages between occupational, indoor, and community air pollution research. *Environmental Health Perspectives,* **110(Suppl 4)**, 573.
Delpla, I., A.-. Jung, E. Baures, M. Clement, and O. and Thomas, 2009: Impacts of climate change on surface water quality in relation to drinking water production. *Environment International,* **35(8)**, 1255-1233.
Deschenes, O., M. Greenstone, and J. Guryan, 2009: Climate Change and Birth Weight. *American Economic Review,* **99(2)**, 211-217.
Desrochers, G., R. Roy, L. Roy, G. Pasher, F. Guay, and D. Tapsoba, 2009: Comparing methods to investigate the impacts of climate change.Proceedings of 2009 AWRA Spring Specialty Conference: Managing Water Resources Development in a Changing Climate, May 4-5, 2009, Anchorage, Alaska, pp. 22.
Diffenbaugh, N.S. and C.B. Field, 2013: Changes in ecologically critical terrestrial climate conditions. *Science,* **341(6145)**, 486-491.
Diffenbaugh, N.S., M. Ashfaq, and M. Scherer, 2011: Transient regional climate change: analysis of the summer climate response in a high-resolution, century-scale, ensemble experiment over the continental United States. *Journal of Geophysical Research,* **116**, D24111.
Diffenbaugh, N.S. and M. Scherer, 2011: Observational and model evidence of global emergence of permanent, unprecedented heat in the 20th and 21st centuries. *Climatic Change,* **107(3-4)**, 615-624.
Diffenbaugh, N.S. and F. Giorgi, 2012: Climate change hotspots in the CMIP5 global climate model ensemble. *Climatic Change,* **114(3-4)**, 813-822.
Diffenbaugh, N.S., M. Scherer, and M. Ashfaq, 2012: Response of snow-dependent hydrologic extremes to continued global warming. *Nature Climate Change,* **3(4)**, 349-384.
Direccion General de Comunicacion Social, 2012: *Por efectos de la sequía, más de dos millones de Mexicanos están en riesgo de hambruna*. Direccion General de Comunicacion Social, .
Dirmeyer, P.A., Y. Jin, B. Singh, and X. Yan, 2013: Evolving land-atmosphere interactions over North America from CMIP5 simulations. *Journal of Climate,* .

Diuk-Wasser, M., G. Vourc'h, P. Cislo, A.G. Hoen, F. Melton, S.a. Hamer, M. Rowland, R. Cortinas, G.J. Hickling, J.I. Tsao, A.G. Barbour, U. Kitron, J. Piesman, and D. Fish, 2010: Field and climate-based model for predicting the density of host-seeking nymphal Ixodes scapularis , an important vector of tick-borne disease agents in the eastern United States. *Global Ecology and Biogeography,* **19(4)**, 504-514.

Dolfman, M.L., S. Fortier Wasser, and B. Bergman, 2007: The Effects of Hurricane Katrina on the New Orleans Economy. *Monthly Labor Review,* **130**, 3-18.

Dombeck, M.P., J.E. Williams, and C.A. Wood, 2004: Wildfire policy and public lands: Integrating scientific understandings with social concerns across landscapes. *Conservation Biology,* **18(4)**, 883-889.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009: Ocean acidification: The other CO₂problem. *Annual Review of Marine Science,* **1**, 169-192.

Douglas, E.M., P.H. Kirshen, M. Paolisso, C. Watson, J. Wiggin, A. Enrici, and M. Ruth, 2012: Coastal flooding, climate change and environmental justice: identifying obstacles and incentives for adaptation in two metropolitan Boston Massachusetts communities. *Mitigation and Adaptation Strategies for Global Change,* **17(5)**, 537-562.

Downing, A. and A. Cuerrier, 2011: A synthesis of the impacts of climate change on the First Nations and Inuit of Canada. *Indian Journal of Traditional Knowledge,* **10(1)**, 57-70.

Doyle, M.W., E.H. Stanley, D.G. Havlick, M.J. Kaiser, G. Steinbach, W.L. Graf, G.E. Galloway, and J.A. Riggsbee, 2008: Aging infrastructure and ecosystem restoration. *Science,* **319(5861)**, 286.

Drake, B.G., L. Hughes, E.A. Johnson, B.A. Seibel, M.A. Cochrane, V.J. Fabry, D. Rasse, and L. Hannah, 2005: Synergistic effects. In: *Climate Change and Biodiversity*. [T.E. Lovejoy and L.J. Hannah (ed.)]. Yale University Press, New Haven, CT, pp. 296-316.

Duffy, P. and C. Tebaldi, 2012: Increasing prevalence of extreme summer temperatures in the US. *Climatic Change,* **111(2)**, 487-495.

Dukes, J.S., N.R. Chiariello, S.R. Loarie, and C.B. Field, 2011: Strong response of an invasive plant species (Centaurea solstitialis L.) to global environmental changes. *Ecological Applications,* **21(6)**, 1887-1894.

Dumais, D. and M. Prévost, 2007: Management for red spruce conservation in Québec: The importance of some physiological and ecological characteristics-A review. *The Forestry Chronicle,* **83(3)**, 378-392.

Dupuis, A.P. and B.J. Hann, 2009: Warm spring and summer water temperatures in small eutrophic lakes of the Canadian prairies: Potential implications for phytoplankton and zooplankton. *Journal of Plankton Research,* **31(5)**, 489-502.

Dwyer, B., B. Harding, E. Wilson, M. Brown, J. Pearce, and J. Smith, 2012: *Colorado River Water Availability Study*. Colorado Water Conservation Board, Denver, CO, pp. 1-189.

Eakin, H., 2006: *Weathering risk in rural Mexico: Economic, climatic and institutional change*. University of Arizona Press, Tuscon, USA, .

Eakin, H. and C. Tucker, 2006: Responding to the coffee crisis: A pilot study of farmers' adaptations in Mexico, Guatemala and Honduras. *The Geographical Journal,* **172(2)**, 156-171.

Eakin, H. and K. Appendini, 2008: Livelihood change, farming, and managing flood risk in the Lerma valley, Mexico. *Agriculture and Human Values,* **25(4)**, 555-566.

Eakin, H., A. Winkels, and J. Sendzimir, 2009: Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. *Environmental Science and Policy,* **12(4)**, 398-412.

Eakin, H., A.M. Lerner, and F. Murtinho, 2010: Adaptive capacity in evolving peri-urban spaces: Responses to flood risk in the Upper Lerma River Valley, Mexico. *Global Environmental Change,* **20(1)**, 14-22.

Eakin, H.C. and A. Patt, 2011: Are adaptation studies effective, and what can enhance their practical impact? *Wiley Interdisciplinary Review: Climatic Change,* **2(2)**, 141-153.

Ebi, K.L., J. Balbus, P.L. Kinney, E. Lipp, D. Mills, M.S. O'Neill, and M. Wilson, 2008: Chapter 2: Effects of global change on human health. In: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*. [Gamble, J.L. (ed.)]. U.S. Environmental Protection Agency, Washington, D.C., pp. 2-1-2-78.

Ebi, K.L., 2011: Resilience to the Health Risks of Extreme Weather Events in a Changing Climate in the United States. *International Journal of Environmental Research and Public Health,* **8(12)**, 4582-4595.

Emberlin, J., M. Detandt, R. Gehrig, S. Jaeger, N. Nolard, and A. Rantio-Lehtimäki, 2002: Responses in the start of Betula (birch) pollen seasons to recent changes in spring temperatures across Europe. *International Journal of Biometeorology,* **46(4)**, 159-170.

Emelko, M.B., U. Silins, K.D. Bladon, and M. and Stone, 2011: Implications of land disturbance on drinking water treatability in a changing climate: Demonstrating the need for "source water supply and protection" strategies. *Water Research,* **45(2)**, 461-472.
Energy Information Administration, 2013: *Annual Energy Outlook 2013*. U.S. Energy Information Administration, U.S. Department of Energy, Washington DC.
Energy, Mines and Resources: Forest Management Branch, 2012: *Forest Health Report 2012*. Government of Yukon, Yukon, Canada, pp. 8-15.
Environment Canada, 2011a: *Federal Adaptation Policy Framework*. Government of Canada, Gatineau, QC.
Environment Canada, 2011b: *Backgrounder: Canada's Ongoing Commitment to Climate Change Adaptation* Government of Canada, Ottawa, Canada, pp. 1.
Environment Canada, 2013a: *Water Availability: Indicator Initiative* Government of Canada, Ottawa, Canada, .
Environment Canada, 2013b: *Regional Freshwater Quality in Canadian Rivers* Government of Canada, Ottawan, Canada, .
Epstein, P., 2010: The ecology of climate change and infectious diseases: comment. *Ecology,* **91(3)**, 925-8; discussion 928-9.
Escolero-Fuentes, O.A., S.E. Martínez, S. Kralisch, and M. Perevochtchikova, 2009: *Vulnerabilidad de las fuentes de abastecimiento de agua potable de la Ciudad de México en el contexto de cambio climático*. Centro Virtual de Cambio Climático, ICyTDF, Instituto de Ciencias de la Atmósfera-UNAM, Instituto de Geología-UNAM, El Colegio de México, Mexico.
Esqueda, G.S., J.E. Ospina-Norena, C. Gay-Garcia, and C. Conde, 2010: Vulnerability of water resources to climate change scenarios. Impacts on the irrigation districts in the Guayalejo-Tamesí river basin, Tamaulipas, México. *Atmósfera,* **24(1)**, 141-155.
Euripidou, E. and V. Murray, 2004: Public health impacts of floods and chemical contamination. *Journal of Public Health,* **26(4)**, 376-383.
Executive Office of the President, 2013: *The President's Climate Action Plan*. The White House, Washington DC.
Feagin, R.A., D.J. Sherman, and W.E. Grant, 2005: Coastal erosion, global sea-level rise, and the loss of sand dune plant habitats. *Frontiers in Ecology and the Environment,* **3(7)**, 359-364.
Federal Emergency Management Agency, 2013: *Questions about the Biggert-Waters Flood Insurance Reform Act of 2012*. Federal Emergency Management Agency.
Feltmate, B. and J. Thistlethwaite, 2012: Insurance: Adapting Building Codes for Climate Change. In: *Climate Change Adaptation: A Priorities Plan for Canada*. University of Waterloo, Waterloo, Ontario, pp. 85-92.
Few, R., K. Brown, and E.L. Tompkins, 2007: Public participation and climate change adaptation: avoiding the illusion of inclusion. *Climate Policy,* **7(1)**, 46-59.
Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott, 2007: North America. Climate Change 2007: Impacts, Adaptation and Vulnerability. In: *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Parry, M.L., O.F. Canziani, J.P. Paulikof, van der Linden, P. J., and C.E. Hanson(eds.)]. Cambridge University Press, Cambridge, UK, pp. 617-652.
Findell, K.L. and T.L. Delworth, 2010: Impact of Common Sea Surface Temperature Anomalies on Global Drought and Pluvial Frequency. *Journal of Climate,* **23(3)**, 485-503.
Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, and A.A. Velichko, 2007: Ecosystems, their properties, goods, and services. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (ed.)]. Cambridge University Press, Cambridge, pp. 211-272.
Flint, C.G., B. McFarlane, and M. Miller, 2008: Human dimensions of forest disturbance by insects: An international synthesis. *Environmental Management,* **43(6)**, 1174-1186.
Flood, J.F. and L.B. Cahoon, 2011: Risks to Coastal Wastewater Collection Systems from Sea-Level Rise and Climate Change. *Journal of Coastal Research,* **27(4)**, 652-660.
Follett, R.F. and D.A. Reed, 2010: Soil carbon sequestration in grazing lands: Societal benefits and policy implications. *Rangeland Ecology and Management,* **63(1)**, 4-15.
Food and Agriculture Organization, 2009: *FAOSTAT: Countries by Commodity, Wheat* Food and Agriculture Organization of the United Nations, .

Food and Agriculture Organization, 2012: *Forests and Climate Change Working Paper 10*. In: Forest Management and Climate Change: a literature review. Food and Agriculture Organization of the United Nations, Rome, pp. 1-55.
Forbes, K.A., S.W. Kienzle, C.A. Coburn, J.M. Byrne, and J. Rasmussen, 2011: Simulating the hydrological response to predicted climate change on a watershed in southern Alberta, Canada. *Climatic Change,* **105(3-4)**, 555-576.
Ford, J.D., T. Pearce, J. Prno, F. Duerden, L.B. Ford, M. Beaumier, and T. Smith, 2010a: Perceptions of climate change risks in primary resource use industries: A survey of the Canadian mining sector. *Regional Environmental Change,* **10(1)**, 65.
Ford, J.D., T. Pearce, J. Prno, F. Duerden, L.B. Ford, T.R. Smith, and M. Beaumier, 2011: Canary in a coal mine: Perceptions of climate change risks and response options among Canadian mine operations. *Climatic Change,* **109(3-4)**, 399-415.
Ford, J.D., T. Pearce, F. Duerden, C. Furgal, and B. Smit, 2010b: Climate change policy responses for Canada's Inuit population: The importance of and opportunities for adaptation. *Global Environmental Change,* **20(1)**, 177-191.
Frank, E., H. Eakin, and D. Lopez-Carr, 2010: Risk perception and adaptation to climate risk in the coffee sector of Chiapas, Mexico.Proceedings of Tropentag 2010: Conference on International Research on Food Security, Natural Resource Management and Rural Development, September 14-16, Zurich, pp. 1-4.
Fraser, E.D., E. Simelton, M. Termansen, S.N. Gosling, and A. South, 2013: “Vulnerability hotspots”: Integrating socio-economic and hydrological models to identify where cereal production may decline in the future due to climate change induced drought. *Agricultural and Forest Meteorology,* **170**, 195-205.
Frazier, T.G., N. Wood, B. Yarnal, and D.H. Bauer, 2010: Influence of potential sea level rise on societal vulnerability to hurricane storm-surge hazards, Sarasota County, Florida. *Applied Geography,* **30(4)**, 490-505.
Frei, T. and E. Gassner, 2008: Climate change and its impact on birch pollen quantities and the start of the pollen season an example from Switzerland for the period 1969–2006. *International Journal of Biometeorology,* **52(7)**, 667-674.
Fried, J.S., J.K. Gilless, W.J. Riley, T.J. Moody, C. Simon de Blas, K. Hayhoe, M. Moritz, S. Stephens, and M. Torn, 2008: Predicting the effect of climate change on wildfire behavior and initial attack success. *Climatic Change,* **87**, 251-264.
Friesinger, S. and P. Bernatchez, 2010: Perceptions of Gulf of St. Lawrence coastal communities confronting environmental change: Hazards and adaptation, Quebec, Canada. *Ocean and Coastal Management,* **53(11)**, 669-678.
Fuchs, A. and H. Wolff, 2010: Concept and unintended consequences of weather index insurance: the case of Mexico. *American Journal of Agricultural Economics,* **93(2)**, 505-511.
Furgal, C. and T. Prowse, 2008: Northern Canada. In: *From Impacts to Adaptation: Canada in a Changing Climate 2007*. [Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush(eds.)]. Government of Canada, Ottawa, pp. 57-118.
Galindo, I., S. Castro, and M. Valdés, 2009: Satellite derived solar irradiance over Mexico. *Atmósfera,* **4(3)**, 189-201.
Galindo, L.M., 2009: *The Economics of Climate Change in Mexico*. Secretaría de Medio Ambiente y Recursos Naturales y Secretaría de Hacienda y Crédito Público, Mexico City.
Gallagher, J., 2012: *Learning about an infrequent event: Evidence from flood insurance take-up in the US*. Department of Economics, University of California at Berkeley, California, pp. 1-47.
Gallivan, F., K. Bailey, and L. O'Rourke, 2009: Planning for Impacts of Climate Change at US Ports. *Transportation Research Record: Journal of the Transportation Research Board,* **2100(1)**, 15-21.
Gamble, J.L., K.L. Ebi, A.E. Grambsch, F.G. Sussman, and T.J. Wilbanks, 2008: *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems (SAP 4.6)*. U.S. Environmental Protection Agency, Washington, D. C., pp. 1-283.
Gasper, R., A. Blohm, and M. Ruth, 2011: Social and economic impacts of climate change on the urban environment. *Current Opinion in Environmental Sustainability,* **3(3)**, 150-157.
Gay, C., F. Estrada, C. Conde, H. Eakin, and L. Villers, 2006: Potential impacts of climate change on agriculture: A case of study of coffee production in Veracruz, Mexico. *Climatic Change,* **79(3-4)**, 259-288.
Gazeau, F., C. Quiblier, J.M. Jansen, J. Gattuso, J.J. Middelburg, and C.H. Heip, 2007: Impact of elevated CO2 on shellfish calcification. *Geophysical Research Letters,* **34(7)**.

Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidgard, T.C. Richmond, K. Reckhow, K. White, and D. Yates, 2013: *Chapter 3: Water Resources*. In: Federal Advisory Committee Draft Climate Assessment Report Released for Public Review.
Georgescu, M., D.B. Lobell, and C.B. Field, 2011: Direct climate effects of perennial bioenergy crops in the United States. *Proceedings of the National Academy of Sciences,* **108(11)**, 4307-4312.
Getches, D.H., 2003: Water management in the United States and the fate of the Colorado River delta in Mexico. *US-Mex.LJ,* **11**, 107.
Girardin, M.P. and D. Sauchyn, 2008: Three centuries of annual area burned variability in northwestern North America inferred from tree rings. *The Holocene,* **18(2)**, 205-214.
Girardin, M.P., A.A. Ali, C. Carcaillet, M. Mudelsee, I. Drobyshev, C. HELy, and Y. Bergeron, 2009: Heterogeneous response of circumboreal wildfire risk to climate change since the early 1900s. *Global Change Biology,* **15(11)**, 2751-2769.
Girardin, M.P., A.A. Ali, C. Carcaillet, S. Gauthier, C. Hély, H. Le Goff, A. Terrier, and Y. Bergeron, 2012: Fire in managed forests of eastern Canada: Risks and options. *Forest Ecology and Management,* .
Gleeson, J., P. Gray, A. Douglas, C.J. Lemieux, and G. Nielsen, 2011: *A practitioner's guide to climate change adaptation in Ontario's ecosystems*. Ontario Centre for Climate Impacts and Adaptation Resources, Sudbury, Ontario, pp. 1-74.
Glick, P. and B.A. Stein, 2011: *Scanning the conservation horizon: A guide to climate change vulnerability assessment*. National Wildlife Federation, Washington, D.C., pp. 1-168.
Gómez-álvarez, A., J.L. Valenzuela-García, D. Meza-Figueroa, M. de la O-Villanueva, J. Ramírez-Hernández, and J. Almendariz-Tapia, 2011: Impact of mining activities on sediments in a semi-arid environment: San Pedro river, Sonora, Mexico. *Applied Geochemistry,* **26(12)**, 2101-2112.
Gomez-Diaz, J.D., A.I. Monterroso-Rivas, J.A.T. Rueda, and M.L.T. Medrano, 2011: Assessing current and potential patterns of 16 forest species driven by climate change scenarios in México. *Atmósfera,* **24(1)**, 31-52.
Gómez-Mendoza, L. and L. Arriaga, 2007: Modeling the effect of climate change on the distribution of oak and pine species of Mexico. *Conservation Biology,* **21(6)**, 1545-1555.
Gong, H., A.T. DeGaetano, and L.C. Harrington, 2011: Climate-based models for West Nile Culex mosquito vectors in the Northeastern US. *International Journal of Biometeorology,* **55(3)**, 435-436.
González Martínez, E., 2006: *Plan Rector de la Cafeticultura Nacional*. Sistema Producto Cafe Nacional; La Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, México, DF.
Goujon, A., W. Lutz, and W. Sanderson, 2004: Future human capital: population projections by level of education. In: *The end of world population growth in the 21st century: New challenges for human capital formation and sustainable development*. pp. 121-141.
Government of Quebec, 2012: *Quebec in Action: Greener by 2020: 2013-2020 Government Strategy for Climate Change Adaptation*. Government of Quebec, Quebec City, Quebec.
Gramig, B.M., J.M. Barnard, and L.S. Prokopy, 2013: Farmer beliefs about climate change and carbon sequestration incentives. *Climate Research,* **56**, 157-167.
Greer, A., V. Ng, and D. Fisman, 2008: Climate change and infectious diseases in North America: the road ahead. *Canadian Medical Association Journal,* **178(6)**, 715.
Grenzeback, L. and A. Luckmann, 2006: *Case Study of the Transportation Sector's Response to and Recovery from Hurricanes Katrina and Rita*. Transportation Research Board, Washington DC.
Groffman, P.M., P. Kareiva, S. Carter, N.B. Grimm, J.J. Lawler, M. Mack, V. Matzek, and H. Tallis, 2013: Chapter 8: Ecosystems, Biodiversity and Ecosystem Services. In: *U.S. National Climate Assessment*. U.S. Global Change Research Program, Washington, D. C., .
Groisman, P.Y., B.G. Sherstyukov, V.N. Razuvaev, R.W. Knight, J.G. Enloe, N.S. Stroumentova, P.H. Whitfield, E. Førland, I. Hannsen-Bauer, and H. Tuomenvirta, 2007: Potential forest fire danger over Northern Eurasia: changes during the 20th century. *Global and Planetary Change,* **56(3)**, 371-386.
Gude, P., R. Rasker, and J. van den Noort, 2008: Potential for future development on fire-prone lands. *Journal of Forestry,* **106(4)**, 198-205.
Hajat, S. and T. Kosatsky, 2010: Heat-related mortality: A review and exploration of heterogeneity. *Journal of Epidemiology and Community Health,* **64(9)**, 753-760.
Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, and C. Hawkins-Hoffman, 2011: *Adapting to climate change at Olympic National Forest and Olympic National Park*. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, .

Hamin, E.M. and N. Gurran, 2009: Urban form and climate change: Balancing adaptation and mitigation in the US and Australia. *Habitat International,* **33(3)**, 238-245.

Hamlet, A., S.Y. Lee, K. Mickelson, and M. Elsner, 2010: Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. *Climatic Change,* **102(1-2)**, 103-128.

Hamlet, A.F., 2011: Assessing water resources adaptive capacity to climate change impacts in the Pacific Northwest Region of North America. *Hydrology and Earth System Sciences,* **15(5)**, 1427-1443.

Hammer, R.B., S.I. Stewart, and V.C. Radeloff, 2009: Demographic trends, the wildland-urban interface, and wildfire management. *Society and Natural Resources,* **22(8)**, 777-782.

Hanna, E.G., T. Kjellstrom, C. Bennett, and K. Dear, 2011: Climate change and rising heat: Population health implications for working people in Australia. *Asia-Pacific Journal of Public Health,* **23(2 SUPPL.)**, 14S-26S.

Hannah, L., P.R. Roehrdanz, M. Ikegami, A.V. Shepard, M.R. Shaw, G. Tabor, L. Zhi, P.A. Marquet, and R.J. Hijmans, 2013: Climate change, wine, and conservation. *Proceedings of the National Academy of Sciences,* **110(17)**, 6907-6912.

Hanson, S., R. Nicholls, N. Ranger, S. Hallegatte, J. Corfee-Morlot, C. Herweijer, and J. Chateau, 2011: A global ranking of port cities with high exposure to climate extremes. *Climatic Change,* , 1-23.

Hardess, L., A. Karst, M. M'Lot, S. Morgan, S. Wolfe, R. Matthews, and R. Sydneysmith, 2011: *Climate Change and Adaptive Capacity in Aboriginal Communities South of 60 Assessment Report*. Centre for Indigenous Environmental Resources, Winnipeg, Manitoba.

Hardoy, J. and P. Romero Lankao, 2011: Latin American cities and climate change: challenges and options to mitigation and adaptation responses. *Current Opinion in Environmental Sustainability,* **3(3)**, 158-163.

Harlan, S.L., A.J. Brazel, L. Prashad, W.L. Stefanov, and L. Larsen, 2006: Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine,* **63(11)**, 2847-2863.

Harlan, S.L., A.J. Brazel, G.D. Jenerette, N.S. Jones, L. Larsen, L. Prashad, and W.L. Stefanov, 2008: In the shade of affluence: The inequitable distribution of the urban heat island. *Research in Social Problems and Public Policy,* **15**, 173-202.

Harlan, S.L. and D.M. Ruddell, 2011: Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Current Opinion in Environmental Sustainability,* **3(3)**, 126-134.

Harper, S.L., V.L. Edge, C. Schuster-Wallace, O. Berke, and S.A. McEwen, 2011: Weather, water quality and infectious gastrointestinal illness in two Inuit communities in Nunatsiavut, Canada: potential implications for climate change. *EcoHealth,* **8(1)**, 93-108.

Hatfield, J.L., R.M. Cruse, and M.D. Tomer, 2013: Convergence of agricultural intensification and climate change in the Midwestern United States: implications for soil and water conservation. *Marine and Freshwater Research,* **64(5)**, 423-435.

Hatfield, J.R., K.J. Boote, B.A. Kimball, D.W. Wolfe, D.R. Ort, R.C. Izaurralde, and G.L. Hahn, 2008: *Agriculture*. In: The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Synthesis and Assessment Product 4.3. [Walsh, M. (ed.)]. U.S. Climate Change Science Program, Washington, D.C., pp. 21-74.

Hayhoe, K., D. Cavan, C. Field, P. Frumhoff, E. Maurer, M.N. Miller, S. Moser, S. Schneider, K.N. Cahill, E. Cleland, L. Dale, and J. Verville, 2004: Emissions pathways, climate change and impacts on California. *Proceedings of the National Academies of Science,* **101(34)**, 12422-12427.

Hayhoe, K., S. Sheridan, L. Kalkstein, and S. Greene, 2010: Climate change, heat waves, and mortality projections for Chicago. *Journal of Great Lakes Research,* **36, Supplement 2(0)**, 65-73.

Heap, N., 2007: *Hot properties: How global warming could transform B.C.'s real estate sector*. David Suzuki Foundation, Vancouver.

Hebben, T., 2009: *Analysis of water quality conditions and trends for the long-term river network: Athabasca River, 1960-2007*. Alberta Environment.

Hejazi, M.I. and M. Markus, 2009: Impacts of urbanization and climate variability on floods in northeastern Illinois. *Journal of Hydrologic Engineering,* **14(6)**, 606-616.

Henstra, D., 2012: Toward the Climate-Resilient City: Extreme Weather and Urban Climate Adaptation Policies in Two Canadian Provinces. *Journal of Comparative Policy Analysis: Research and Practice,* **14(2)**, 175-194.

Hernandez, A., B. Dominguez, P. Cervantes, S. Munoz-Melgarejo, S. Salazar-Lizan, and A. Tejeda-Martinez, 2011: Temperature-humidity index (*THI*) 1917-2008 and future scenarios of livestock comfort in Veracruz, México. *Atmósfera,* **24(1)**, 89-102.

Hernández, L., H. Reyes-Bonilla, and E.F. Balart, 2010: Efecto del blanqueamiento del coral por baja temperatura en los crustáceos decápodos asociados a arrecifes del suroeste del golfo de California. *Revista Mexicana De Biodiversidad,* **81**, S113-S119.

Hicke, J.A., C.D. Allen, A.R. Desai, M.C. Dietze, R.J. Hall, E.H. (Ted) Hogg, D.M. Kashian, D. Moore, K.F. Raffa, R.N. Sturrock, and J. Vogelmann, 2012: Effects of biotic disturbances on forest carbon cycling in the United States and Canada. *Global Change Biology,* **18(1)**, 7-34.

Hirsch, R.M. and K.R. Ryberg, 2012: Has the magnitude of floods across the USA changed with global CO2 levels? *Hydrological Sciences Journal,* **57(1)**, 1-9.

Hoegh-Guldberg, O., L. Hughes, S. McIntyre, D.B. Lindenmayer, C. Parmesan, H.P. Possingham, and C.D. Thomas, 2008: Assisted colonization and rapid climate change. *Science,* **321(5887)**, 345-346.

Hoerling, M.P., J.K. Eischeid, X.W. Quan, H.F. Diaz, R.S. Webb, R.M. Dole, and D.R. Easterling, 2012: Is a transition to semipermanent drought conditions imminent in the U.S. Great Plains? *Journal of Climate,* **25(8380)**, 8386.

Hogg, E.H. and P.Y. Bernier, 2005: Climate change impacts on drought-prone forest in western Canada. *The Forestry Chronicle,* **81(5)**, 675-682.

Hogg, E.H., J.P. Brandt, and M. Michaelian, 2008: Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests. *Canadian Journal of Forest Research,* **38(6)**, 1373-1384.

Holden, Z.A., P. Morgan, M.A. Crimmins, R.K. Steinhorst, and A.M. Smith, 2007: Fire season precipitation variability influences fire extent and severity in a large southwestern wilderness area, United States. *Geophysical Research Letters,* **34(16)**, L16708.

Holloway, T., S.N. Spak, D. Barker, M. Bretl, C. Moberg, K. Hayhoe, J. Van Dorn, and D. Wuebbles, 2008: Change in ozone air pollution over Chicago associated with global climate change. *Journal of Geophysical Research,* **113(D22)**, 1-14.

Holmes, J., 2010: The forestry industry. In: *What Do We Know? What Do We Need to Know? The State of Canadian Research on Work, Employment and Climate Change*. [Lipsig-Mummé, C. (ed.)]. Work in a Warming World Research Programme, York University, Toronto, pp. 149-167.

Hori, M.E., D. Nohara, and H.L. Tanaka, 2007: Influence of Arctic Oscillation towards the Northern Hemisphere surface temperature variability under the global warming scenario. *Journal of the Meteorological Society of Japan,* **85(6)**, 847-859.

Horton, B. and G.R.A. Richardson, 2011: *Climate change adaptation and Canadian municipal and business decision-makers: A snapshot of 2009*. In: CCIAD Discussion Paper Series. Natural Resources Canada, Ottawa, Canada.

Houle, D., A. Bouffard, L. Duchesne, T. Logan, and R. Harvey, 2012: Projections of future soil temperature and water content for three southern Quebec forested sites. *Journal of Climate,* **25(21)**, 7690-7701.

Howden, S.M., J.F. Soussana, F.N. Tubiello, N. Chhetri, M. Dunlop, and H. Meinke, 2007: Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences,* **104(50)**, 19691-19696.

Huber-Sannwald, E., F.T. Maestre, J.E. Herrick, and J.F. Reynolds, 2006: Ecohydrological feedbacks and linkages associated with land degradation: a case study from Mexico. *Hydrological Processes,* **20(15)**, 3395-3411.

Hunt, A. and P. Watkiss, 2011: Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change,* **104(1)**, 13-49.

Hurd, B.H. and J. Coonrod, 2012: Hydro-economic Consequences of Climate Change in the Upper Rio Grande. *Climate Research,* **53(2)**, 103-118.

Hurtado-Díaz, M., H. Riojas-Rodríguez, A. Brito-Hernández, and W. Junger, 2011: Temperature, air pollution and pediatric hospitalizations in Mexico City.Proceedings of 23rd Annual Conference of the International Society for Environmental Epidemiology (ISEE) 2011, September 13-16, 2011, .

Hurteau, M.D. and M. North, 2010: Carbon recovery rates following different wildfire risk mitigation treatments. *Forest Ecology and Management,* **260(5)**, 930-937.

Hurteau, M.D., M.T. Stoddard, and P.Z. Fulé, 2011: The carbon costs of mitigating high-severity wildfire in southwestern ponderosa pine. *Global Change Biology,* **17(4)**, 1516-1521.

Hystad, P.W. and P.C. Keller, 2006: Disaster management: Kelowna tourism industry's preparedness, impact and response to a 2003 major forest fire. *Journal of Hospitality and Tourism Management,* **13(1)**, 44-58.

Hystad, P.W. and P.C. Keller, 2008: Towards a destination tourism disaster management framework: Long-term lessons from a forest fire disaster. *Tourism and Management,* **29(1)**, 151-162.

Institute of Medicine, 2011: *Climate Change, the Indoor Environment, and Health*. The National Academies Press, Washington, D.C., pp. 286.

Instituto Mexicano de Tecnología del Agua, 2010: *Efectos del Cambio Climático en los Recursos Hídricos de México, Volumen III. Atlas de Vulnerabilidad Hídrica en México ante el Cambio Climático*. Instituto Mexicano de Tecnología del Agua, México.

Instituto Nacional de Ecología y Cambio Climático, 2006: *Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre Cambio Climático (CMNUCC) [Third National Communication to the UN Framework Convention on Climate Change (UNFCCC)]*. Secretaria de Medio Ambiente y Recursos Naturales, Mexico, D.F.

Instituto Nacional de Ecología y Cambio Climático, 2012a: *Quinta Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*. Secretaria de Medio Ambiente y Recursos Naturales, México, D.F.

Instituto Nacional de Ecología y Cambio Climático, 2012b: *Adaptación al cambio climático en México: visión, elementos y criterios para la toma de decisiones*. Secretaría de Medio Ambiente y Recursos Naturales, Mexico, Mexico City.

Insurance Institute for Business and Home Safety, 2011: *Rating the States: An Assessment of Residential Building Code and Enforcement Systems for Life Safety and Property Protection in Hurricane-Prone Regions*. Insurance Institute for Business and Home Safety, Tampa, Florida.

Insurance Institute for Business and Home Safety, 2012: *Fortified for Safer Living: Builders' Guide*. IBHS, Tampa, Florida.

International Boundary and Water Commission, 2012: *Commission Signs Colorado River Agreement*. In: News and Press Releases. International Boundary and Water Commission United States Section, El Paso, Texas.

International Council for the Exploration of the Sea, 2011: Report of the Study Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN).Proceedings of ICES CM 2011/SSGSUE:01, November 15-19, 2010, Woods Hole, Massachusetts, US, pp. 155.

International Institute for Applied System Analysis, 2007: *GGI Downscaled Spatially Explicit Socio-Economic Scenario Data* Greenhouse Gas Initiative (GGI) Program of the International Institute for Applied Systems Analysis, .

Intersecretarial Commission on Climate Change, 2007: *National Strategy on Climate Change: Mexico*. Government of Mexico, Mexico City.

IPCC, 2012: *Summary for Policymakers. In:Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. In: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-., Allen, S.K., Tignor, M. and Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge U.K. and New York, USA.

Isaac, M. and D.P. Van Vuuren, 2009: Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy,* **37(2)**, 507-512.

Ivers, L.C. and E.T. Ryan, 2006: Infectious diseases of severe weather-related and flood-related natural disasters. *Current Opinion in Infectious Diseases,* **19(5)**, 408.

Jaakkola, J.J.K., B.F. Hwang, and N. Jaakkola, 2005: Home dampness and molds, parental atopy, and asthma in childhood: a six-year population-based cohort study. *Environmental Health Perspectives,* **113(3)**, 357.

Jacob, D.J. and D.A. Winner, 2009: Effect of climate change on air quality. *Atmospheric Environment,* **43(1)**, 51-63.

Jacques, L., C. De Vit, and F. Gagnon-Lebrun, 2010: *Status of Climate Change Adaptation in Canada's Agricultural Sector*. Government of Canada Policy Research Initiative.

Janetos, A., L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, W. Peterson, and R. Shaw, 2008: *Biodiversity*. In: The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Synthesis and Assessment Product 4.3 [Walsh, M. (ed.)]. U.S. Climate Change Science Program, Washington, DC, pp. 21-74.

Jantarasami, L.C., J.L. Lawler, and C.W. Thomas, 2010: Institutional Barriers to Climate Change Adaptation in U.S. National Parks and Forests. *Ecology and Society,* **15(4)**, 33.

Jimenez-Moleon, M.C. and M.A. Gomez-Albores, 2011: Waterborne diseases in the state of Mexico, Mexico (2000-2005). *Journal of Water and Health,* **9(1)**, 200-7.

Johansson, M.A., D.A.T. Cummings, and G.E. Glass, 2009: Multiyear climate variability and dengue--El Nino southern oscillation, weather, and dengue incidence in Puerto Rico, Mexico, and Thailand: a longitudinal data analysis. *PLoS Medicine,* **6(11)**, e1000168.
Johnston, M., T. Williamson, E. Wheaton, V. Wittrock, H. Nelson, H. Hesseln, L. Vandamme, J. Pittman, and M. Lebel, 2008: *Limited Report: Climate Change Adaptive Capacity of Forestry Stakeholders in the Boreal Plains Ecozone*. In: Climate Change Impacts and Adaptation Program Project A1383. Saskatchewan Research Council, Saskatoon, SK.
Johnston, M., T. Williamson, A. Munson, A. Ogden, M. Moroni, R. Parsons, D. Price, and J. Stadt, 2010: *Climate change and forest management in Canada: impacts, adaptive capacity and adaptation options. A State of Knowledge report*. Sustainable Forest Management Network, Edmonton, Alberta, pp. 16-35.
Jones, G.V., M.A. White, O.R. Cooper, and K. Storchmann, 2005: Climate Change and Global Wine Quality. *Climatic Change,* **73**, 319-343.
Jonkman, S.N., B. Maaskant, E. Boyd, and M.L. Levitan, 2009: Loss of life caused by the flooding of New Orleans after Hurricane Katrina: analysis of the relationship between flood characteristics and mortality. *Risk Analysis,* **29(5)**, 676-698.
Jury, M.R., 2008: Climate influence on dengue epidemics in Puerto Rico. *International Journal of Environmental Health Research,* **18(5)**, 323-34.
Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray, 2008: *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean and US Pacific Islands*. In: Synthesis and Assessment Product 3.3: Report by the US Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Climate Change Science Program, Washington DC.
Keel, B.G. (ed.), 2007: *Assisted Migration as a Conservation Strategy for Rapid Climatic Change: Investigating Extended Photoperiod and Mycobiont Distribution forHabenaria repens Nuttall (Orchidaceae) as a Case Study*. Diss. PhD, Antioch University, 1-160 pp.
Keeley, J.E. and P.H. Zedler, 2009: Large, high-intensity fire events in southern California shrublands: debunking the fine-grain age patch model. *Ecological Applications,* **19(1)**, 64-94.
Keim, M.E., 2008: Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *American Journal of Preventive Medicine,* **35(5)**, 508-516.
Kelly, G., 2010: Built to a new code. *Canadian Underwriter,* **8**, 48-50.
Kelly, J., P.A. Makar, and D.A. Plummer, 2012: Projections of mid-century summer air quality for North America: Effects of changes in climate and precursor emissions. *Atmospheric Chemistry and Physics,* **12**, 3875-3940.
Kelly, A.E. and M.L. Goulden, 2008: Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences,* **105(33)**, 11823-11826.
Kemp, A., B.P. Horton, S.J. Culver, D.R. Corbett, O. Van De Plassche, and R. Edwards, 2008: Early Onset of Historical Accelerated Relative Sea Level Rise in North Carolina, USA.Proceedings of Geological Society of America Annual Meeting 2008, 2008, Houston, Texas, .
Kenny, G.F., J. Yardley, C. Brown, R.J. Sigal, and O. Jay, 2010: Heat stress in older individuals and patients with common chronic diseases. *Canadian Medical Association Journal,* **182(10)**, 1053-1060.
Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin, 2009: *Estimated use of water in the United States in 2005*. US Geological Survey Reston, VA, .
Kenter, P., 2010: Climate change adaptation missing. *Daily Commercial News and Construction Record,* **83(97)**.
Kerkhoven, E. and T.Y. Gan, 2011: Differences and sensitivities in potential hydrologic impact of climate change to regional-scale Athabasca and Fraser River basins of the leeward and windward sides of the Canadian Rocky Mountains respectively. *Climatic Change,* **106(4)**, 583-607.
Kharin, V.V., F.W. Zwiers, X. Zhang, and M. Wehner, 2013: Changes in temperature and precipitation extremes in the CMIP5 ensemble. *Climatic Change,* **119(2)**, 345-357.
Kienzle, S.W., M.W. Nemeth, J.M. Byrne, and R.J. MacDonald, 2012: Simulating the hydrological impacts of climate change in the upper North Saskatchewan River basin, Alberta, Canada. *Journal of Hydrology,* **412**, 76-89.
King County Department of Natural Resources and Parks, 2008: *Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise*. King County (WA) Department of Natural Resources and Parks, Wastewater Treatment Division, Seattle, Washington, pp. 1-13.
Kinney, P.L., 2012: Health: A new measure of health effects. *Nature Climate Change,* **2(4)**, 233-234.

Kinney, P., M. Oneill, M. Bell, and J. Schwartz, 2008: Approaches for estimating effects of climate change on heat-related deaths: challenges and opportunities. *Environmental Science & Policy,* **11(1)**, 87-96.

Kinney, P., P. Sheffield, R.S. Ostfeld, J. Carr, R. Leichenko, and P. Vancura, 2011: Chapter 11: Public Health. In: *Responding to Climate Change in New York State: the ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State*. [Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, and P. Grabhorn(eds.)]. New York State Energy Research and Development Authority, Albany, NY, pp. 397-438.

Kinney, P.L., 2008: Climate change, air quality, and human health. *American Journal of Preventive Medicine,* **35(5)**, 459-67.

Kirchner, J.W., C.M. Austin, A. Myers, and D.C. Whyte, 2011: Quantifying remediation effectiveness under variable external forcing using contaminant rating curves. *Environmental Science and Technology,* **45(18)**, 7874-7881.

Kirshen, P., M. Ruth, and W. Anderson, 2006: Chapter 7: Climate's Long-term Impacts on Urban Infrastructures and Services: The Case of Metro Boston. In: *Regional Climate Change And Variability: Impacts And Responses*. [Ruth, M., K. Donaghy, and P.H. Kirshen(eds.)]. Edward Elgar Publishers, Cheltenham, England, pp. 191-225.

Kirshen, P., K. Knee, and M. Ruth, 2008: Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies. *Climatic Change,* **90(4)**, 453-473.

Kjellstrom, T., R.S. Kovats, S.J. Lloyd, T. Holt, and R.S.J. Tol, 2009: The direct impact of climate change on regional labor productivity. *Archives of Environmental and Occupational Health,* **64(4)**, 217-227.

Kjellstrom, T. and J. Crowe, 2011: Climate change, workplace heat exposure, and occupational health and productivity in central America. *International Journal of Occupational and Environmental Health,* **17(3)**, 270-281.

Klerkx, L. and C. Leeuwis, 2009: Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technological Forecasting and Social Change,* **76**, 849-860.

Knowlton, K., M. Rotkin-Ellman, G. King, H.G. Margolis, D. Smith, G. Solomon, R. Trent, and P. English, 2009: The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environmental Health Perspectives,* **117(1)**, 61-67.

Knowlton, K., J.E. Rosenthal, C. Hogrefe, B. Lynn, S. Gaffin, R. Goldberg, C. Rosenzweig, K. Civerolo, J. Ku, and P.L. Kinney, 2004: Assessing Ozone-Related Health Impacts under a Changing Climate. *Environmental Health Perspectives,* **112(15)**, 1557-1563.

Knutson, T.R., J.L. McBride, J. Chan, K. Emanual, G. Holland, C. Landsea, I. Held, J.P. Kossin, A.K. Srivastava, and M. Sugi, 2010: Tropical cyclones and climate change. *Nature Geosciences,* **3**, 157-163.

Koffi, J.K., P.A. Leighton, Y. Pelcat, L. Trudel, L.R. Lindsay, F. Milord, and N.H. Ogden, 2012: Passive surveillance of I. scapularis ticks: Enhanced analysis for early detection of emerging Lyme disease risk. *Journal of Medical Entomology,* **49(2)**, 400-409.

Kolden, C.A. and T.J. Brown, 2010: Beyond wildfire: perspectives of climate, managed fire, and policy in the USA. *International Journal of Wildland Fire,* **19**, 364-373.

Kolivras, K., 2010: Changes in dengue risk potential in Hawaii, USA, due to climate variability and change. *Climate Research,* **42(1)**, 1-11.

Kovacs, J.M., J. Malczewski, and F. Flores-Verdugo, 2004: Examining local ecological knowledge of hurricane impacts in a mangrove forest using an analytical hierarchy process (AHP) approach. *Journal of Coastal Research,* **20(3)**, 792-800.

Kovacs, P., 2005: Promoting resilient homes. *Canadian Underwriter,* **May 2005**, 36-40.

Kovats, R.S. and S. Hajat, 2008: Heat stress and public health: A critical review. *Annual Review of Public Health,* **29**, 41-55.

Krishnamurthy, P.K., J.B. Fisher, and C. Johnson, 2011: Mainstreaming local perceptions of hurricane risk into policymaking: A case study of community GIS in Mexico. *Global Environmental Change,* **21**, 143-153.

Kucharik, C.J. and S.P. Serbin, 2008: Impacts of recent climate change on Wisconsin corn and soybean yield trends. *Environmental Research Letters,* **3(3)**, 034003.

Kulshreshtha, S., 2011: Climate change, prairie agriculture, and prairie economy: the new normal. *Canadian Journal of Agricultural Economics,* **59**, 19-44.

Kumar, S., V. Merwade, J. Kam, and K. Thurner, 2009: Streamflow trends in Indiana: Effects of long term persistence, precipitation and subsurface drains. *Journal of Hydrology,* **374(1)**, 171-183.

Kumar, S., V. Merwade, J.L. Kinter III, and D. Niyogi, 2013a: Evaluation of Temperature and Precipitation Trends and Long-term Persistence in CMIP5 20th Century Climate Simulations. *Journal of Climate,* .

Kumar, S., S.I. Kinter, P.A. Dirmeyer, Z. Pan, and J.M. Adams, 2013b: Multi-decadal Climate Variability and the "Warming Hole" in North America–results from CMIP5 20th and 21st Century Climate Simulations. *Journal of Climate,* **26(11)**, 3511-3527.

Kundzewicz, Z., L. Mata, N.W. Arnell, P. Döll, B. Jimenez, K. Miller, T. Oki, Z. Sen, and I. Shiklomanov, 2008: The implications of projected climate change for freshwater resources and their management. *Hydrological Sciences Journal,* **53(1)**, 3-10.

Kunkel, K.E., K.E. Bromirski, H.E. Brooks, T. Cavazos, A.V. Douglas, D.R. Easterling, K.A. Emanuel, P.Y. Groisman, G.J. Holland, T.R. Knutson, J.P. Kossin, P.D. Komar, P.D. Levinson, and R.L. Smith, 2008: *Observed Changes in Weather and Climate Extremes in Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*. [Karl, T.R., Meehl, G.A., Miller, C.D., Hassol, S.J., Waple, A.M. and Murray, W.L. (eds.)]. U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

Kunkel, K.E., H.-. Huang, X.-. Liang, J.-. Lin, D. Wuebbles, Z. Tao, A. Williams, M. Caughey, J. Zhu, and K. Hayhoe, 2007: Sensitivity of future ozone concentrations in the northeast USA to regional climate change. *Mitigation and Adaptation Strategies for Global Change,* **13(5-6)**, 597-606.

Kunreuther, H.C. and E.O. Michel-Kerjan, 2009: *At War with the Weather: Managing Large Scale Risks in a New Era of Catastrophes*. Massachusetts Institute of Technology Press, .

Kurz, W.A., C.C. Dymond, G. Stinson, G.J. Rampley, E.T. Neilson, A.L. Carroll, T. Ebata, and L. Safranyik, 2008a: Mountain pine beetle and forest carbon feedback to climate change. *Nature,* **452(24)**, 987-990.

Kurz, W.A., G. Stinson, G.J. Rampley, C.C. Dymond, and E.T. Neilson, 2008b: Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. *Proceedings of the National Academy of Sciences,* **105(5)**, 1551-1555.

Lafferty, K.D., 2009: The ecology of climate change and infectious diseases. *Ecology,* **90(4)**, 888-900.

Lal, P., J. Alavalapati, and D.E. Mercer, 2011: Socio-economic impacts of climate change on rural United States. *Mitigation and Adaptation Strategies for Global Change,* **16**, 819-844.

Lambrechts, L., K.P. Paaijmans, T. Fansiri, L.B. Carrington, and L.D. Kramer, 2011: Impact of daily temperature fluctuations on dengue virus transmission by Aedes aegypti. *Proceedings of the National Academy of Sciences,* **108(21)**, 7460-7465.

Laukkonen, J., P.K. Blanco, J. Lenhart, M. Keiner, B. Cavric, and C. Kinuthia-Njenga, 2009: Combining climate change adaptation and mitigation measures at the local level. *Habitat International,* **33(3)**, 287-292.

Lazo, J.K., M. Lawson, P.H. Larsen, and D.M. Waldman, 2011: U.S. Economic Sensitivity to Weather Variability. *Bulletin of the American Meteorological Society,* **6**, 709-720.

Leal Asencio, M.T., D.V. Millán Gómez, C.G. Méndez Jaime, and C.A. Servín Jungdorf, 2008: *Evaluación de la afectación de la calidad del agua en cuerpos de agua superficiales y subterráneos por efecto de la variabilidad y el cambio climático y su impacto en la biodiversidad, agricultura, salud, turismo e industria [Assessment of the impacts on surface and groundwater due to climate change and the cliamte variability and effects on biodiversity, agriculture, health tourims and the industry]*. Secretaria de Medio Ambiente y Recursos Naturales, Mexico, pp. 123.

Lee, J., S. Gryze, and J. Six, 2011: Effect of climate change on field crop production in California's Central Valley. *Climatice Change,* **109(1)**, 335-353.

Leichenko, R., 2011: Climate change and urban resilience. *Current Opinion in Environmental Sustainability,* **3(3)**, 164-168.

Leighton, P.A., J.K. Koffi, Y. Pelcat, L.R. Lindsay, and N.H. Ogden, 2012: Predicting the speed of tick invasion: An empirical model of range expansion for the Lyme disease vector Ixodes scapularis in Canada. *Journal of Applied Ecology,* **49(2)**, 457-464.

Leon, C. and C. Neri, 2010: *Case study: Mexico City*. In: Climate Change, Disaster Risk Management and the Urban Poor. The World Bank, pp. 217-233.

Leonard, L., J. Dorton, S. Culver, and R. Christian, 2009: *Coastal and estuarine observing in North Carolina: Integrating observations and science to understand our coastal environment*. East Carolina University Press, Carolina, USA, pp. 30.

Leurig, S., 2011: *Climate Risk Disclosure by Insurers: Evaluating insurer responses to the NAIC climate disclosure survey*. Ceres, Boston, MA.

Levetin, E. and d.W. Van, 2008: Changing pollen types/concentrations/distribution in the United States: fact or fiction? *Current Allergy and Asthma Reports,* **8(5)**, 418-24.
Levina, E., J.S. Jacob, L.E. Ramos, and I. Ortiz, 2007: *Policy frameworks for adaptation to climate change in coastal zones: The case of the Gulf of Mexico*. Organisation for Economic Co-operation and Development, Paris, France.
Liao, K., E. Tagaris, K. Manomaiphiboon, C. Wang, J. Woo, P. Amar, S. He, and A.G. Russell, 2009: Quantification of the impact of climate uncertainty on regional air quality. *Atmospheric Chemistry and Physics,* **9(3)**, 865-878.
Liao, K., E. Tagaris, K. Manomaiphiboon, S.L. Napelenok, J. Woo, S. He, P. Amar, and A.G. Russell, 2007: Sensitivities of ozone and fine particulate matter formation to emissions under the impact of potential future climate change. *Environmental Science & Technology,* **41(24)**, 8355-61.
Liceaga-Correa, M.A., L.U. Arellano-Méndez, and H. Hernández--Núñez, 2011: Efectos de los huracanes y cambio climático sobre el Caribe mexicano: adaptabilidad de los pastos marinos. In: *Vulnerabilidad de las zonas costeras mexicanas ante el cambio climático*. [Botello, A.V., S. Villanueva-Fragoso, J. Gutiérrez, and J.L. Rojas Galaviz(eds.)]. Gobierno del estado de Tabasco, Semarnat-INE, UNAM-ICMyL, Universidad Autónoma de Campeche, Mexico, pp. 211-228.
Lin, B.B., 2007: Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. *Agricultural and Forest Meteorology,* **144(1-2)**, 85-94.
Lin, B.B., 2010: The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agroecosystems. *Agricultural and Forest Meteorology,* **150**, 510-518.
Lin, J., K.O. Patten, K. Hayhoe, X. Liang, and D.J. Wuebbles, 2008: Effects of Future Climate and Biogenic Emissions Changes on Surface Ozone over the United States and China. *Journal of Applied Meteorology and Climatology,* **47(7)**, 1888-1909.
Lin, J., D.J. Wuebbles, H. Huang, Z. Tao, M. Caughey, X. Liang, J. Zhu, and T. Holloway, 2010: Potential effects of climate and emissions changes on surface ozone in the Chicago area. *Journal of Great Lakes Research,* **36**, 59-64.
Liu, J., C. Folberth, H. Yang, J. Röckström, K. Abbaspour, and A.J. Zehnder, 2013: A global and spatially explicit assessment of climate change impacts on crop production and consumptive water use. *PLoS ONE,* **8(2)**, e57750.
Liu, Y., S. L Goodrick, and J. A Stanturf, 2012: Future US wildfire potential trends projected using a dynamically downscaled climate change scenario. *Forest Ecology and Management,* .
Lo, E. and E. Levetin, 2007: Influence of meteorological conditions on early spring pollen in the Tulsa atmosphere from 1987-2006. *Journal of Allergy and Clinical Immunology,* **119(1)**, S101-S101.
Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly, 2009: The velocity of climate change. *Nature,* **462(7276)**, 1052-1055.
Lobell, D.B. and C.B. Field, 2011: California perennial crops in a changing climate. *Climate Change,* **109(1)**, 317-333.
Lobell, D.B., U.L.C. Baldos, and T.W. Hertel, 2013: Climate adaptation as mitigation: the case of agricultural investments. *Environmental Research Letters,* **8(1)**, 015012.
Lobell, D.B., C.B. Field, K.N. Cahill, and C. Bonfils, 2006: Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties. *Agricultural and Forest Meteorology,* **141(2)**, 208-218.
Lobell, D.B., S. Wolfram, and J. Costa-Roberts, 2011: Climate Trends and Global Crop Production Since 1980. *Science,* **333(6042)**, 616-620.
Locke, P., C. Clifton, and S. Westra, 2011: Extreme weather events and the mining industry. *Engineering and Mining Journal,* **212(3)**, 58.
Lozano-Fuentes, S., M.H. Hayden, C. Welsh-Rodriguez, C. Ochoa-Martinez, B. Tapia-Santos, K.C. Kobylinski, C.K. Uejio, E. Zielinski-Gutierrez, L. Delle Monache, A.J. Monaghan, D.F. Steinhoff, and L. Eisen, 2012: The Dengue Virus Mosquito Vector Aedes aegypti at High Elevation in México. *American Journal of Tropical Medicine and Hygiene,* **87(5)**, 902-909.
Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle, 2007: *Envisioning futures for the Sacramento-San Joaquin Delta*. Public Policy Institute of California, San Francisco, USA, pp. 285.
MacDonald, G.M., 2010: Water, climate change, and sustainability in the southwest. *Proceedings of the National Academy of Sciences,* **107(50)**, 21256-21262.

Macias Fauria, M. and E.A. Johnson, 2006: Large-scale climatic patterns control large lightning fire occurrence in Canada and Alaska forest regions. *Journal of Geophysical Research,* **111(G04008)**.
Macias Fauria, M. and E.A. Johnson, 2008: Climate and wildfires in the North American boreal forest. *Philosophical Transactions of the Royal Society B,* **363**, 2317-2329.
MacKendrick, N. and J. Parkins, 2005: *Social Dimensions of Community Vulnerability to Mountain Pine Beetle*. In: Mountain Pine Beetle Initiative Working Paper 2005-26. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.
Magana, V., 2010: Climate Change, Disaster Risk Management and the Urban Poor Mexcio City Case Study. In: *Estudio de vulnerabilidad diferenciada ante eventos extremos del clima en la zona metropolitan de la ciudad de México: Aspectos climáticos* [Leon, C. and C. Neri(eds.)]. World Bank, Washington, D.C., pp. 72-114.
Magrin, G., C.G. Garcia, D.C. Choque, J.C. Giménez, A.R. Moreno, G.J. Nagy, C. Nobre, and A. Villamiza, 2007: *Chapter 13 - Latin America, IPCC WGII Fourth Assessment Report*., pp. 63.
Mahmud, a., M. Hixson, J. Hu, Z. Zhao, S.-. Chen, and M.J. Kleeman, 2010: Climate impact on airborne particulate matter concentrations in California using seven year analysis periods. *Atmospheric Chemistry and Physics,* **10(22)**, 11097-11114.
Mailhot, A. and S. Duchesne, 2010: Design Criteria of Urban Drainage Infrastructures under Climate Change. *Journal of Water Resources Planning and Management,* **136(2)**, 201-208.
Mansourian, S., A. Belokurov, and P.J. Stephenson, 2009: The role of forest protected areas in adaptation to climate change. *Unasylva,* **60(1-2)**, 63-68.
Mantua, N., I. Tohver, and A. Hamlet, 2010: Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change,* **102(1-2)**, 187-223.
Marlin, A., L. Olsen, D. Bruce, J. Ollerhead, K. Singh, J. Heckman, B. Walters, D. Meadus, and A. Hanson, 2007: *Examining Community Adaptive Capacity to Address Climate Change, Sea Level Rise, and Salt Marsh Restoration in Maritime Canada*. Rural and Small Town Program, Sackville, NB.
Marshall, E. and T. Randhir, 2008: Effect of climate change on watershed system: A regional analysis. *Climatic Change,* **89(3-4)**, 263-280.
Marshall, G.R., 2013: Transaction costs, collective action and adaptation in managing complex social–ecological systems. *Ecological Economics,* **88**, 185-194.
Marshall, N.A., S.E. Park, W.N. Adger, K. Brown, and S.M. Howden, 2012: Transformational capacity and the influence of place and identity. *Environmental Research Letters,* **7(3)**, 034022.
Martiello, M.A. and M.V. Giacchi, 2010: Review Article: High temperatures and health outcomes: A review of the literature. *Scandinavian Journal of Public Health,* **38(8)**, 826-837.
Martin, W.E., I.M. Martin, and B. Kent, 2009: The role of risk perceptions in the risk mitigation process: The case of wildfire in high risk communities. *Journal of Environmental Management,* **91**, 489-498.
Martinez Arroyo, A., S. Manzanilla Naim, and J. Zavala Hidalgo, 2011: Vulnerability to climate change of marine and coastal fisheries in México. *Atmosfera,* **24(1)**, 103-123.
Maryland Commission on Climate Change Adaptation and Response Working Group, 2008: *Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change: Phase I: Sea-level rise and coastal storms*. Maryland Department of Natural Resources, Annapolis, Maryland.
Maryland Department of the Environment on behalf of the Maryland Commission on Climate Change, 2010: *Update to Governor and General Assembly*. Maryland Department of the Environment, Annapolis, Maryland.
Matthews, S.N., L.R. Iverson, A.M. Prasad, and M.P. Peters, 2011: Changes in potential habitat of 147 North American breeding bird species in response to redistribution of trees and climate following predicted climate change. *Ecography,* **260**, 1460-1472.
Mawdsley, J.R., R. O'Malley, and D.S. Ojima, 2009: A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology,* **23(5)**, 1080-1089.
Mazari-Hiriart, M., Y. Lopez-Vidal, S. Ponce-de-Leon, J.J. Calva, F. Rojo-Callejas, and C.-. Gonzalo, 2005: Longitudinal study of microbial diversity and seasonality in the Mexico City metropolitan area water supply system. *Applied and Environmental Microbiology,* **71(9)**, 5129-5137.
McBoyle, G.D., Scott, and B. Jones, 2007: Climate change and the future of snowmobiling in non-mountainous regions of Canada. *Managing Leisure,* **12**, 237-250.
McDonald, T., 2012: *Coastal Impacts, Adaptation, and Vulnerabilities: A Technical Input to the 2013 National Climate Assessment*. Island Press, .

McFarlane, B.L., 2006: *Human dimensions of fire management in the wildland-urban interface: A literature review*. In: Canadian Wildland Fire Strategy: Background, Syntheses, Analyses, and Perspectives. [Kirsch, K.G. and Fuglem, P. (eds.)]. Canadian Council for Forest Ministries, Edmonton, Alberta, CA, pp. 27-34.
McGranahan, G., D. Balk, and B. Anderson, 2007: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization,* **19(1)**, 17.
McGregor, G.R., 2011: Human biometeorology. *Progress in Physical Geography,* **36(1)**, 93-109.
McKee, K.L., 2011: Biophysical controls on accretion and elevation change in Caribbean mangrove ecosystems. *Estuarine, Coastal and Shelf Science,* **91**, 475-483.
McKenzie, D., Z. Gedalof, D.L. Peterson, and P. Mote, 2004: Climatic change, wildfire, and conservation. *Conservation Biology,* **18(4)**, 890-920.
McLeman, R. and G. Gilbert, 2008: *Economic and social adaptation to climate change in Canadian seasonal-economy communities*. In: Final Scientific Report for Natural Resources Canada, Project A1319. Natural Resources Canada, Ottawa, Canada.
McLeman, R.A., 2010: Impacts of population change on vulnerability and the capacity to adapt to climate change and variability: a typology based on lessons from 'a hard country'. *Population & Environment,* **31(5)**, 286-316.
McMichael, A.J., P. Wilkinson, R.S. Kovats, S. Pattenden, S. Hajat, B. Armstrong, N. Vajanapoom, E.M. Niciu, H. Mahomed, and C. Kingkeow, 2008: International study of temperature, heat and urban mortality: the 'ISOTHURM'project. *International Journal of Epidemiology,* **37(5)**, 1121-1131.
Medina-Ramon, M. and J. Schwartz, 2007: Temperature, Temperature Extremes, and Mortality: A Study of Acclimatization and Effect Modification in 50 United States Cities. *Occupational and Environmental Medicine,* **64(12)**, 827-833.
Meehl, G.A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel, 2009: Relative increase of record high maximum temperatures compared to record low minimum temperatures in the U.S. *Geophysical Research Letters,* **36(23)**, L23701.
Meehl, G.A., J.M. Arblaster, and G. Branstator, 2012: Mechanisms contributing to the warming hole and the consequent US east-west differential of heat extremes. *Journal of Climate,* **25(18)**, 6394–6408.
Megdal, S.B. and C.A. Scott, 2011: The Importance of Institutional Asymmetries to the Development of Binational Aquifer Assessment Programs: The Arizona-Sonora Experience. *Water,* **3(3)**, 949-963.
Mehta, V.K., V.R. Haden, B.A. Joyce, D.R. Purkey, and L.E. Jackson, 2013: Irrigation demand and supply, given projections of climate and land-use change, in Yolo County, California. *Agricultural Water Management,* **117**, 70-82.
Mercer, K.L., H.R. Perales, and J.D. Wainwright, 2012: Climate change and the transgenic adaptation strategy: Smallholder livelihoods, climate justice, and maize landraces in Mexico. *Global Environmental Change,* **22(2)**, 495-504.
Meyer, M.D., E. Rowan, C. Snow, and A. Choate, 2013: *Impacts of Extreme Weather on Transportation: National Symposium Summary*. American Association of State Highway and Transportation Officials, Washington, D.C., pp. 20.
Meza-Figueroa, D., R.M. Maier, M. de la O-Villanueva, A. Gómez-Alvarez, A. Moreno-Zazueta, and J. Rivera, 2009: The impact of unconfined mine tailings in residential areas from a mining town in a semi-arid environment: Nacozari, Sonora, Mexico. *Chemosphere,* **77(1)**, 140-147.
Miao, S., F. Chen, Q. Li, and S. Fan, 2011: Impacts of Urban Processes and Urbanization on Summer Precipitation: A Case Study of Heavy Rainfall in Beijing on 1 Aug 2006. *Journal of Applied Meteorology and Climatology,* **50**, 806-825.
Michaelian, M., E.H. Hogg, R.J. Hall, and E. Arsenault, 2011: Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. *Global Change Biology,* **17(6)**, 2084-2094.
Millar, C.I., N.L. Stephenson, and S.S. Stephens, 2007: Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications,* **17(8)**, 2145-2151.
Miller, A.W., A.C. Reynolds, C. Sobrino, and G.F. Riedel, 2009: Shellfish face uncertain future in high CO2 world: influence of acidification on oyster larvae calcification and growth in estuaries. *PLoS One,* **4(5)**, e5661.
Millerd, F., 2011: The potential impact of climate change on Great Lakes international shipping. *Climatic Change,* **104(3-4)**, 629-652.
Mills, B.N., S.L. Tighe, J. Andrey, J.T. Smith, and K. Huen, 2009: Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada. *Journal of Transportation Engineering,* **135(10)**, 773-782.

Mills, E. and E. Lecomte, 2006: *From Risk to Opportunity: How Insurers can proactively and profitably manage climate change*. Ceres, Boston, MA.

Mills, E., 2007: *From Risk to Opportunity 2007: Insurer responses to climate change*. Ceres.

Mills, E., 2009: A global review of insurance industry responses to climate change. *Geneva Papers on Risk & Insurance,* **34(3)**, 323-359.

Mills, E., 2012: The greening of insurance. *Science,* **338**, 1424-1425.

Minero, F.J.G., P. Candau, J. Morales, and C. Tomas, 1998: Forecasting olive crop production based on ten consecutive years of monitoring airborne pollen in Andalusia (southern Spain). *Agriculture, Ecosystems & Environment,* **69(3)**, 201-215.

Ministry of Municipal Affairs and Housing, 2011: *Potential changes for the next edition of the Building Code: Second Round of Consultation (February-April 2011)*. Queen's Printer for Ontario, Toronto, pp. 46.

Minville, M., F. Brissette, S. Krau, and R. Leconte, 2009: Adaptation to climate change in the management of a Canadian water-resources system exploited for hydropower. *Water Resources Management,* **23(14)**, 2965-6986.

Mirza, M.S. and M. Haider, 2003: *The State of Infrastructure in Canada: Implications for Infrastructure Planning and Policy*. McGill University, Montreal.

Molnar, J.J., 2010: Climate change and societal response: Livelihoods, communities, and the environment. *Rural Sociology,* **75(1)**, 1-16.

Monkkonen, P., 2011: The Housing Transition in Mexico: Expanding Access to Housing Finance. *Urban Affairs Review,* **47(5)**, 672-695.

Montero Martinez, J., J. Martinez, N.I. Castillo, and B.E. Espinoza, 2010: Capitulo 2. Escenarios climáticos en México proyectados para el siglo XXI: precipitación y temperaturas máxima y mínima [Chapter 2. Climate scenarios projected for the twenty-first century in Mexico: precipitation and maximum and minimum temperatures]. In: *Atlas de vulnerabilidad hídrica en México ante el cambio climático [Atlas of water vulnerability to climate change in Mexico]*. Secretaría del Medio Ambiente y Recursos Naturales, Mexico, D.F., pp. 41-63.

Monterroso Rivas, A.I., C.C. Alvarez, G.R. Dorantes, and J.D.G. Diaz, 2011: Assessing current and potential rainfed maize suitability under climate change scenarios in Mexico. *Atmosfera,* **24(1)**, 53-67.

Monterroso, A., C. Conde, C. Gay, D. Gómez, and J. López, 2012: Two methods to assess vulnerability to climate change in the Mexican agricultural sector. *Mitigation and Adaptation Strategies for Global Change,* , 1-17.

Moran, D., A. Lucas, and A. Barnes, 2013: Commentary: Mitigation win-win. *Nature Climate Change,* **3**, 611-613.

Morello-Frosch, R., M. Pastor Jr, C. Porras, and J. Sadd, 2002: *Environmental Health Perspectives,* **110(Suppl 2)**, 149.

Morin, C.W. and A.C. Comrie, 2010: Modeled response of the West Nile virus vector Culex quinquefasciatus to changing climate using the dynamic mosquito simulation model. *International Journal of Biometeorology,* **54(5)**, 517-29.

Moritz, C., C. Hoskin, J. MacKenzie, B. Phillips, M. Tonione, N. Silva, J. VanDerWal, S. Williams, and C. Graham, 2009: Identification and dynamics of a cryptic suture zone in tropical rainforest. *Proceedings of the Royal Society B: Biological Sciences,* **276(1660)**, 1235-1244.

Morton, T., P. Bretschneider, D. Coley, and T. Kershaw, 2011: Building a better future: An exploration of beliefs about climate change and perceived need for adaptation within the building industry. *Building and Environment,* **46**, 1151-1158.

Mortsch, L., J. Bhatti, R. Lal, M. Apps, and M. Price, 2006: Impact of climate change on agriculture, forestry and wetlands. In: Taylor & Francis, CRC Press, Boca Raton, FL, pp. 45-67.

Moser, C. and D. Satterthwaite, 2008: *Towards pro-poor adaptation to climate change in the urban centres of low- and middle-income countries*. World Bank.

Moser, S.C. and J.A. Ekstrom, 2010: A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences,* **107(51)**, 22026-22031.

Moser, S.C., 2013: Navigating the political and emotional terrain of adaptation: Community engagement when climate change comes home. In: *Successful Adaptation to Climate Change: Linking Science and Practice in a Rapidly Changing World*. [Moser, S.C. and M.T. and Boykoff(eds.)]. Routledge, London, pp. 289.

Mote, P.W., 2006: Climate-driven variability and trends in mountain snowpack in western North America. *Journal of Climate,* **19**, 6209-6220.

Mumby, P.J., I.A. Elliott, C.M. Eakin, W. Skirving, C.B. Paris, H.J. . Edwards, S. Enríquez, R. Iglesias-Prieto, L.M. Cherubin, and J.R. Stevens, 2011: Reserve design for uncertain responses of coral reefs to climate change. *Ecology Letters,* **14**, 132-140.

Mumme, S.P., 1999: Managing acute water scarcity on the U.S.-Mexico border: Institutional issues raised by the 1990's drought. *Natural Resources Journal,* **39(1)**, 149-166.

Munich Re, 2011: *Topics Geo Natural Catastrophes 2010*. In: Topics Geo. Munich Re.

Munich Re, 2012: *Severe Weather in North America: Perils, Risks, Insurance*. In: Knowledge Series: Natural Hazards. Munich Re, Munich, Germany.

Murazaki, K. and P. Hess, 2006: How does climate change contribute to surface ozone change over the United States? *Journal of Geophysical Research,* **111**, 1-16.

Nadler, A.J. and P.R. Bullock, 2011: Long-term changes in heat and moisture related to corn production on the Canadian Prairies. *Climatic Change,* **104**, 339-352.

Naeher, L.P., M. Brauer, M. Lipsett, J.T. Zelikoff, C.D. Simpson, J.Q. Koenig, and K.R. Smith, 2007: Woodsmoke health effects: a review. *Inhalation Toxicology,* **19(1)**, 67-106.

Najjar, R.G., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M.R. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood, 2010: Potential climate-change impacts on the Chesapeake Bay. *Estuarine, Coastal and Shelf Science,* **86**, 1-20.

Nakaegawa, T., A. Kitoh, and M. Hosaka, 2013: Discharge of major global rivers in the late 21st century climate projected with the high horizontal resolution MRI-AGCMs. *Hydrological Processes,* .

Nakashima, D.J., K. Galloway McLean, H.D. Thulstrup, A. Ramos Castillo, and J.T. Rubis, 2011: Proceedings of the Expert Workshop on Indigenous Peoples, Marginalized Populations and Climate Change.Proceedings of Indigenous Peoples, Marginalized Populations and Climate Change, July 19-21, 2011, Mexico City, Mexico, .

NatCatSERVICE, 2010: *Data source for Chart 24.4 Population projections, children and seniors* Statistics Canada, Canada.

National Climate Assessment Development Advisory Committee, 2013: *Draft National Climate Assessment Report*. U.S. Global Change Research Program, Washington D.C.

National Climate Data Center, 2013: *State of the Climate: Wildfires for Annual 2012* U.S. National Oceanographic and Atmospheric Administration, National Climate Data Center, Asheville NC, .

National Energy Board, 2011: *Canada's Energy Future: Energy Supply and Demand Projections to 2035*. National Energy Board, Ottawa.

National Oceanic and Atmospheric Administration, 2010: *Adapting to Climate Change: A Planning Guide for State Coastal Managers*. NOAA Office of Ocean and Coastal Resource Management, Silver Spring, MD, pp. 1-132.

National Oceanic and Atmospheric Administration, 2013: *Service Assessment: Hurricane/Post-Tropical Cyclone Sandy October 22–29, 2012*. U.S. Department of Commerce, Silver Spring, Maryland.

National Research Council, 2010: *America's Climate Choices: Panel on Adapting to the Impact of Climate Change*. The National Academies Press, Washington D.C.

National Round Table on the Environment and the Economy, 2012: *Facing the Elements: Building Business Resilience in a Changing Climate (Case Studies)*. National Round Table on the Environment and the Economy, Ottawa.

National Water Commission of Mexico, 2010: *Statistics on Water in Mexico, 2010 edition*. [Ministry of Environment and Natural Resources (ed.)], Mexico.

Natural Resources Canada, 2008: *From impacts to adaptation: Canada in a changing climate 2007*. [Lemmen, D.S., Warren, F.J., Lacroix, J. and Bush, E. (eds.)]. Government of Canada, Ottawa, ON, pp. 119-170.

Natural Resources Canada, 2011: *Canada's Regional Adaptation Collaborative Program - Helping Canadians prepare for and adapt to climate change*. Government of Canada, Ottawa, Canada.

Natural Resources Canada, 2013: *Adaptation Platform* Natural Resources Canada, Ottawa, .

Nawrotski, R.J., F. Riosmena, and L.M. Hunter, 2013: Do rainfall deficits predict U.S.-bound migration from rural Mexico? Evidence from the Mexican Census. *Population Research Policy Review,* **32**, 129-158.

Nelson, G.C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee, 2009: *Climate Change: Impact on Agriculture and Costs of Adaptation*. International Food Policy Research Institute, Washington, DC, USA.

Neria, Y. and J.M. Shultz, 2012: Mental health effects of hurricane Sandy: characteristics, potential aftermath, and response. *JAMA: The Journal of the American Medical Association,* **308(24)**, 2571.

New York City Department of Environmental Protection, 2008: *Columbia University Center for Climate Systems Research and HydroQual Environmental Engineers and Scientists*. Columbia University Center for Climate Systems Research and HydroQual Environmental Engineers and Scientists, New York, NY.
New York State Climate Action Council, 2012: *Climate Action Plan Interim Report*. New York State Climate Action Council.
Newland, K., D.R. Agunias, and A. Terrazas, 2008: *Learning by doing: experiences of circular migration*. In: Insight: Programs on Migrants, Migration, and Development. Migration Policy Institute, Washington, D.C., pp. 1-28.
Newswire, 2011: Thai flooding impact spreads across world for Toyota. *Reuters,* .
Nicholls, R., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Château, and R. Muir-Wood, 2008: *Ranking port cities with high exposure and vulnerability to climate extremes*. In: OECD Environment Working Papers, No. 1. OECD Publishing, pp. 1-62.
Nielsen-Gammon, J.W., 2011: *The 2011 Texas Drought. A Briefing Packet for the Texas Legislature*. The Office of the State Climatologist Report, Texas A&M University, College Station.
Niven, R.V., N.M. Hutson, L. Loftus-Otway, and L.B. Boske, 2010: Transportation Infrastructure Planning in Mexico.Proceedings of Transportation Research Board 89th Annual Meeting, .
Nolte, C.G., A.B. Gilliland, C. Hogrefe, and L.J. Mickley, 2008: Linking global to regional models to assess future climate impacts on surface ozone levels in the United States. *Journal of Geophysical Research,* **113**, 1-14.
Nordstrom, D.K., 2009: Acid rock drainage and climate change. *Journal of Geochemical Exploration,* **100(2-3)**, 97-104.
North, M., B.M. Collins, and S. Stephens, 2012: Using fire to increase the scale, benefits, and future maintenance of fuels treatments. *Journal of Forestry,* **110(7)**, 392-401.
Ntelekos, A.A., M. Oppenheimer, J.A. Smith, and A.J. Miller, 2010: Urbanization, climate change and flood policy in the united states. . *Climatic Change,* **103(3)**, 597-616.
Nunavut Department of Sustainable Development, 2003: *Nunavut Climate Change Strategy*. Nunavut Department of Sustainable Development, Iqaluit, Nunavut.
Obeysekera, J., M. Irizarry, J. Park, J. Barnes, and T. Dessalegne, 2011: Climate change and its implications for water resources management in south florida. . *Stochastic Environmental Research and Risk Assessment,* **25(4)**, 495-516.
Ogden, A.E. and J.L. Innes, 2009: Application of structured decision making to an assessment of climate change vulnerabilities and adaptation options for sustainable forest management. *Ecology and Society,* **14(1)**, 11.
Ogden, N.H., L. St-Onge, I.K. Barker, S. Brazeau, M. Bigras-Poulin, D.F. Charron, C.M. Francis, A. Heagy, L.R. Lindsay, A. Maarouf, P. Michel, F. Milord, C. O'Callaghan J., L. Trudel, and R.A. Thompson, 2008: Risk maps for range expansion of the Lyme disease vector, Ixodes scapularis, in Canada now and with climate change. *International Journal of Health Geographics,* **7**, 24-24.
Okey, T.A., H.M. Alidina, A. Montenegro, V. Lo, and S. Jessen, 2012: *Climate change impacts and vulnerabilities in Canada's Pacific marine ecosystems*. World Wildlife Fund/Canadian Parks and Wilderness Society, Vancouver, Vancouver, BC, pp. 1-157.
O'Neill, M.S. and K.L. Ebi, 2009: Temperature extremes and health: impacts of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine,* **51(1)**, 13.
Ontario Ministry of Environment, 2011: *Climate Ready: Ontario's Adaptation Strategy and Action Plan 2011-2014*. Queen's Printer for Ontario, pp. 124.
Oppenheimer, M., 2013: Climate change impacts: accounting for the human response. *Climatic Change,* **117**, 439-449.
Organisation for Economic Co-operation and Development, 2010: *Chapter 1. General Assessment of the Macroeconomic Situation*. In: OECD Economic Outlook Volume 2010/2. OECD Publishing, pp. 1-344.
Orlowsky, B. and S.I. Senevirantne, 2013: Elusive drought: Uncertainty in observed trends and short- and long-term CMIP5 projections. *Hydrology and Earth System Sciences,* **17**, 1765-1781.
Ouellet, C., D. Saint-Laurent, and F. Normand, 2012: Flood events and flood risk assessment in relation to climate and land-use changes: Saint-François River, southern Québec, Canada. *Hydrological Sciences Journal,* **57(2)**, 313-325.
Overpeck, J. and B. Udall, 2010: Dry Times Ahead. *Science,* **328(5986)**, 1642-1643.
Pan, Z., R.W. Arritt, E.S. Takle, W.J.J. Gutowski, C.J. Anderson, and M. Segal, 2004: Altered hydrologic feedback in a warming climate introduces a "warming hole". *Geophysical Research Letters,* **31(17)**, L17109.

Park, W.A., C.D. Allen, A.K. Macalady, D. Griffin, C.A. Woodhouse, D.M. Meko, T.W. Swetnam, S.A. Rauscher, R. Seager, H. Grissino-Mayer, J.S. Dean, E.R. Cook, C. Gangodagamage, M. Cai, and N.G. McDowell, 2013: Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change,* **3**, 292-297.

Parkins, J.R. and N.A. MacKendrick, 2007: Assessing community vulnerability: A study of the mountain pine beetle outbreak in British Columbia, Canada. *Global Environmental Change,* **17**, 460-471.

Parkins, J.R., 2008: The metagovernance of climate change: Institutional adaptation to the mountain pine beetle epidemic in British Columbia. *Journal of Rural and Community Development,* **3(2)**, 7-26.

Parmesan, C., 2006: Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics,* **37**, 637-669.

Parris, A., C. Simpson, and S. Abdelrahim, 2010: *RISA Workshop Report: Looking Ahead at Climate Service, Assessment, and Adaptation*. National Oceanographic and Atmospheric Administration, Climate Program Office, Silver Spring, Maryland.

Patriquin, M.N., A.M. Wellstead, and W.A. White, 2007: Beetles, trees and people: Regional economic impact sensitivity and policy considerations related to the mountain pine beetle infestation in British Columbia, Canada. *Forest Policy and Economics,* **9**, 938-946.

Patz, J., S.J. Vavrus, C.K. Uejio, and S.L. McLellan, 2008: Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S. *American Journal of Preventive Medicine,* **35(5)**, 451-458.

Paudel, K.P. and L.U. Hatch, 2012: Global warming, impact on agriculture and adaptation strategy. *Natural Resource Modeling,* **25(3)**, 456-481.

Peach, J. and J. Williams, 2007: Population and Economic Dynamics on the U.S.-Mexican Border: Past, Present, and Future. In: *The U.S.-Mexican Border Environment: A Road Map to a Sustainable 2020*. [Ganster, P. (ed.)]. SCERP and SDSU Press, San Diego, CA, .

Pearce, T.D., J.D. Ford, J. Prno, F. Duerden, J. Pittman, M. Beaumier, L. Berrang-Ford, and B. Smit, 2011: Climate change and mining in Canada. *Mitigation and Adaptation Strategies for Global Change,* **16(3)**, 347-368.

Pearson, C.J., D. Bucknell, and G.P. Laughlin, 2008: Modelling crop productivity and variability for policy and impacts of climate change in eastern Canada. *Environmental Modelling & Software,* **23**, 1345-1355.

Peng, C., Z. Ma, X. Lei, Q. Zhu, H. Chen, W. Wang, S. Liu, W. Li, X. Fang, and X. Zhou, 2011: A drought-induced pervasive increase in tree mortality across Canada's boreal forests. **1(9)**, 467-471.

Perkins, B., D. Ojima, and R. Corell, 2007: *A survey of climate change adaptation planning*. The H. John Heinz III Center for Science, Economics and the Environment, pp. 1-52.

Peter, B., S. Want, T. Mogus, and B. Wilson, 2006: *Fire risk and population trends in Canada's wildland-urban interface*. In: Canadian Wildland Fire Strategy: Background, Syntheses, Analyses, and Perspectives [Kirsch, K.G. and Fuglem, P. (eds.)]. Canadian Council for Forest Ministries, Edmonton, Alberta, CA, pp. 37-48.

Peterson, T.C., R.R. Heim Jr, R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmair, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B.S. Silva, B.G. Stewart, A.V. Vecchia, G. Villiarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, G.A. Woodhouse, and D. Wuebbles, 2013: Monitoring and understanding changes in heat waves, cold waves, floods and droughts in the United States: State of Knowledge. *Bulletin of the American Meteorological Society,* **94(6)**, 821-834.

Peterson, T.C. and M.O. Baringer, 2009: State of the Climate in 2008. *Bulletin of the American Meteorological Society,* **90**, S1-S196.

Peterson, T.C., X. Zhang, M. Brunet-India, and J.L. Vázquez-Aguirre, 2008: Changes in North American extremes derived from daily weather data. *Journal of Geophysical Research,* **113**, 7113.

Phillips, O.L., L. Aragao, S.L. Lewis, J.B. Fisher, J. Lloyd, G. Lopez-Gonzalez, Y. Malhi, A. Monteagudo, J. Peacock, and C.A. Quesada, 2009: Drought sensitivity of the Amazon rainforest. *Science,* **323(5919)**, 1344-1347.

Picketts, I.M., J. Curry, and E. Rapaport, 2012: Community Adaptation to Climate Change: Environmental Planners' Knowledge and Experiences in British Columbia, Canada. *Journal of Environmental Policy & Planning,* **14(2)**, 119-137.

Pielke Jr, R.A., J. Gratz, C.W. Landsea, D. Collins, M.A. Saunders, and R. Musulin, 2008: Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review,* **9(1)**, 29.

Pierce, J. and G. Meyer, 2008: Long-term fire history from alluvial fan sediments: the role of drought and climate variability, and implications for management of Rocky Mountain forests. *International Journal of Wildland Fire,* **17(1)**, 84-95.
Pinkerton, K.E., W.N. Rom, M. Akpinar-Elci, J.R. Balmes, H. Bayram, O. Brandli, J.W. Hollingsworth, P.L. Kinney, H.G. Margolis, W.J. Martin, E.N. Sasser, K.R. Smith, and T.K. Takaro, 2012: An Official American Thoracic Society Workshop Report: Climate Change and Human Health. *Proceedings of the American Thoracic Society,* **9(1)**, 3-8.
Poiani, K.A., R.L. Goldman, J. Hobson, J.M. Hoekstra, and K.S. Nelson, 2011: Redesigning biodiversity conservation projects for climate change: examples from the field. *Biodiversity and Conservation,* **20(1)**, 185-201.
Poirier, B. and R.C. de Loë, 2012: Protecting aquatic ecosystems in heavily-allocated river systems: the case of the Oldman River Basin, Alberta. *The Canadian Geographer,* **55(2)**, 243-261.
Ponce-Reyes, R., E. Nicholson, P.W. Baxter, R.A. Fuller, and H. Possingham, 2013: Extinction risk in cloud forest fragments under climate change and habitat loss. *Diversity and Distributions,* **19(5-6)**, 518-529.
Population Division, Department of Economic and Social Affairs, 2011: *World Population Prospects: The 2010 Revision and World Urbanization Prospects* United Nations, .
Porter, J.R. and M.A. Semenov, 2005: Crop responses to climatic variation. *Philosophical Transactions of the Royal Society B-Biological Sciences,* **360**, 2021-2035.
Portmann, R.W., S. Solomon, and G.C. Hegerl, 2009: Spatial and seasonal patterns in climate change, temperatures, and precipitation across the United States. *Proceedings of the National Academy of Sciences,* **106**, 7324.
Posey, J., 2009: The determinants of vulnerability and adaptive capacity at the municipal level: Evidence from floodplain management programs in the United States. *Global Environmental Change,* **19(4)**, 482-493.
Potera, C., 2011: Indoor air quality: Climate change impacts indoor environment. *Environmental Health Perspectives,* **119(9)**, A382.
Powell, T., D. Hanfling, and L. Gostin, 2012: Emergency preparedness and public health: the lessons of Hurricane Sandy. *JAMA Online,* , 12-189.
Praskievicz, S. and H. Chang, 2011: Impacts of climate change and urban development on water resources in the Tualatin River Basin, Oregon. *Annals of the Association of American Geographers,* **101(2)**, 249-271.
Pratchett, M.S., P.L. Munday, S.K. Wilson, N.A.J. Graham, J.E. Cinner, D.R. Bellwood, G.P. Jones, N.V.C. Polunin, and T.R. McClanahan, 2008: Effects of climate-induced coral bleaching on coral-reef fishes-ecological and economic consequences. *Oceanography and Marine Biology: An Annual Review,* **46**, 251-296.
Preston, B.L., R.M. Westaway, and E.J. Yuen, 2011: Climate Adaptation Planning in Practice: an Evaluation of Adaptation Plans from Three Developed Nations. *Mitigation and Adaptation Strategies for Global Change,* **16(4)**, 407.
Prieto-González, R., V.E. Cortés-Hernández, and M.J. Montero-Martínez, 2011: Variability of the standardized precipitation index over México under the A2 climate change scenario. *Atmosfera,* **24(3)**, 243-249.
Prokoph, A., J. Adamowski, and K. Adamowski, 2012: Influence of the 11year solar cycle on annual streamflow maxima in Southern Canada. *Journal of Hydrology,* **442**, 55-62.
Pryor, S.C., R.J. Barthelmie, D.T. Young, E.S. Takle, R.W. Arritt, D. Flory, W.J.J. Gutowski, A. Nunes, and J. Roads, 2009: Wind speed trends over the contiguous United States. *Journal of Geophysical Research: Atmospheres (1984-2012),* **114(D14)**, D14105.
Pye, H.O.T., H. Liao, S. Wu, L.J. Mickley, D.J. Jacob, D.K. Henze, and J.H. Seinfeld, 2009: Effect of changes in climate and emissions on future sulfate-nitrate-ammonium aerosol levels in the United States. *Journal of Geophysical Research,* **114**, 1-18.
Quist, D. and I.H. Chapela, 2001: Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. *Nature,* **414(6863)**, 541-543.
Racherla, P.N. and P.J. Adams, 2009: U.S. ozone air quality under changing climate and anthropogenic emissions. *Environmental Science & Technology,* **43(3)**, 571-7.
Radeloff, V.C., R.B. Hammer, S.I. Stewart, J.S. Fried, S.S. Holcomb, and J.S. McKeefry, 2005: The Wildland-Urban Interface in the United States. *Ecological Applications,* **15(3)**, 799-805.
Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme, 2008: Cross-scale Drivers of Natural Disturbances Prone to Anthropogenic Amplification: The Dynamics of Bark Beetle Eruptions. *Bioscience,* **58(6)**, 501-517.

Ramos, M.M., H. Mohammed, E. Zielinski-Gutierrez, M.H. Hayden, J.L.R. Lopez, M. Fournier, A.R. Trujillo, R. Burton, J.M. Brunkard, L. Anaya-Lopez, A.A. Banicki, P.K. Morales, B. Smith, J. Munoz L., and S.H. Waterman, 2008: Epidemic dengue and dengue hemorrhagic fever at the Texas-Mexico border: results of a household-based seroepidemiologic survey, December 2005. *The American Journal of Tropical Medicine and Hygiene,* **78(3)**, 364-9.

Rasmussen, A., 2002: The effects of climate change on the birch pollen season in Denmark. *Aerobiologia,* **18(3)**, 253-265.

Ray, A., J. Vogel, J.B. Smith, and P. Kovacs, 2013: *Adaptation to Climate Change in the United States: Examples from Municipalities, Water Resources, and Insurance*. Stratus Consulting, Boulder, CO.

Reba, M.L., D. Marks, A. Winstral, T.E. Link, and M. Kumar, 2011: Sensitivity of the snowcover energetics in a mountain basin to variations in climate. *Hydrological Processes,* **25(21)**, 3312-3321.

Reisen, F. and S.K. Brown, 2009: Australian firefighters' exposure to air toxics during bushfire burns of autumn 2005 and 2006. *Environment International,* **35(2)**, 342-352.

Reisen, F., D. Hansen, and C. Meyer, 2011: Exposure to bushfire smoke during prescribed burns and wildfires: Firefighters' exposure risks and options. *Environment International,* **37(2)**, 314-321.

Reiss, N.M. and S.R. Kostic, 1976: Pollen season severity and meteorologic parameters in central New Jersey. *The Journal of Allergy and Clinical Immunology,* **57(6)**, 609-14.

Reiter, P., 2008: Climate change and mosquito-borne disease : knowing the horse before hitching the cart. *Revue Scientifique Et Technique - Office International Des Epizooties,* **27(2)**, 383-398.

Repetto, R., 2008: *The Climate Crisis and the Adaptation Myth*. In: Working Paper Number 13 [Coppock, J. (ed.)]. Yale School of Forestry and Environmental Studies, pp. 1-20.

Reuters, 2012: USACE Fighting to Keep Mississippi River Open. *gCaptain,* .

Richardson, G.R.A., 2010: *Adapting to Climate Change: An Introduction for Canadian Municipalities*. Government of Canada, Natural Resources Canada, Ottawa, pp. 1-40.

Riojas-Rodriguez, H., M. Hurtado-Diaz, G.L. Moreno-Banda, and A. Castaneda Martinez, 2011: Mapping Human Health Vulnerability to Climate Change in México. *In: Environmental health perspectives* Proceedings of 23rd Annual Conference of the International Society for Environmental Epidemiology (ISEE) 2011, Sept 13-16, 2011, Barcelona, Spain, .

Rittmaster, R., W. Adamowicz, B. Amiro, and R.T. Pelletier, 2006: Economic analysis of health effects from forest fires. *Canadian Journal of Forest Research,* **36(4)**, 868-877.

Romero-Lankao, P., 2010: Water in Mexico City: what will climate change bring to its history of water-related hazards and vulnerabilities? *Environment and Urbanization,* **22(1)**, 157.

Romero-Lankao, P., 2007: How do local governments in Mexico City manage global warming? *Local Environment,* **12(5)**, 519-535.

Romero-Lankao, P., 2012: Governing Carbon and Climate in the Cities: An Overview of Policy and Planning Challenges and Options. *European Planning Studies,* **20(1)**, 7-26.

Romero-Lankao, P., H. Qin, S. Hughes, Borbor-Cordova M., and M. and Haeffner, 2012a: Urban Vulnerability and Adaptation to the Health Impacts of Air Pollution and Climate Extremes in Latin American Cites. In: *Urban Areas and Global Climate Change Research in Urban Sociology*. Emerald Group Publishing, pp. 247-274.

Romero-Lankao, P., S. Hughes, A. Rosas-Huerta, R. Borquez, and D. Gnatz, 2013a: Urban Institutional Response Capacity for Climate Change: An examination of construction and pathways in Mexico City and Santiago. *Environment and Planning C,* (In press).

Romero-Lankao, P. and D. Dodman, 2011: Cities in transition: transforming urban centers from hotbeds of GHG emissions and vulnerability to seedbeds of sustainability and resilience: Introduction and Editorial overview. *Current Opinion in Environmental Sustainability,* **3(3)**, 113-120.

Romero-Lankao, P. and H. Qin, 2011: Conceptualizing urban vulnerability to global climate and environmental change. *Current Opinion in Environmental Sustainability,* **3(3)**, 142-149.

Romero-Lankao, P., H. Qin, and K. Dickinson, 2012b: Urban vulnerability to temperature-related hazards: A meta-analysis and meta-knowledge approach. *Global Environmental Change,* **22(3)**, 670-683.

Romero-Lankao, P., H. Qin, and M. Borbor-Cordova, 2013b: Exploration of health risks related to air pollution and temperature in three Latin American cities. *Social Science & Medicine,* **83**, 110-118.

Romsdahl, R., L. Atkinson, and J. Schultz, 2013: Planning for climate change across the US Great Plains: concerns and insights from government decision-makers. *Journal of Environmental Studies and Sciences,* **3**, 1-14.

Rood, S.B., J. Pan, K.M. Gill, C.G. Franks, G.M. Samuelson, and A. Shepherd, 2008: Declining summer flows of Rocky Mountain rivers: Changing seasonal hydrology and probable impacts on floodplain forests. *Journal of Hydrology,* **349(3)**, 397-410.

Roorda, M.J., A. Páez, C. Morency, R. Mercado, and S. Farber, 2010: Trip generation of vulnerable populations in three Canadian cities: A spatial ordered probit approach. *Transportation,* **37(3)**, 525-548.

Root, T.L., D.P. MacMynowski, M.D. Mastrandrea, and S.H. Schneider, 2005: Human-modified temperatures induce species changes: joint attribution. *Proceedings of the National Academy of Sciences,* **102(21)**, 7465-7469.

Rose, S. and R. Shaw, 2008: The gamble: Circular Mexican migration and the return on remittances. *Mexican Studies/Estudios Mexicanos,* **24(1)**, 79-111.

Rose, J.B., P.R. Epstein, E.K. Lipp, B.H. Sherman, S.M. Bernard, and J.a. Patz, 2001: Climate variability and change in the United States: potential impacts on water- and foodborne diseases caused by microbiologic agents. *Environmental Health Perspectives,* **109 Suppl**, 211-21.

Rosenthal, J., 2009: Climate change and the geographic distribution of infectious diseases. *EcoHealth,* **6(4)**, 489-95.

Rosenzweig, 2007: Assessment of observed changes and responses in natural and managed systems. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (ed.)]. Cambridge University Press, Cambridge, UK, pp. 79-131.

Rosenzweig, C., D.C. Major, K. Demong, C. Stanton, R. Horton, and M. Stults, 2007: Managing climate change risks in New York City's water system: assessment and adaptation planning. *Mitigation and Adaptation Strategies for Global Change,* **12(8)**, 1391-1409.

Rosenzweig, C. and W. Solecki, 2010: Introduction to climate change adaptation in New York City: building a risk management response. *Annals of the New York Academy of Sciences,* **1196(1)**, 13-18.

Rosenzweig, C., W. Solecki, S.A. Hammer, and S. Mehrotra, 2010: Cities lead the way in climate-change action. *Nature,* **467(7318)**, 909-911.

Rosenzweig, C., W.D. Solecki, R. Blake, M. Bowman, C. Faris, V. Gornitz, R. Horton, K. Jacob, A. LeBlanc, and R. Leichenko, 2011: Developing coastal adaptation to climate change in the New York City infrastructure-shed: process, approach, tools, and strategies. *Climatic Change,* **106(1)**, 93-127.

Ruddell, D., S.L. Harlan, S. Grossman-Clarke, and G. Chowell, 2011: Scales of perception: public awareness of regional and neighborhood climates. *Climatic Change,* **111(3-4)**, 581-607.

Ruggiero, P., C.A. Brown, P.D. Komar, J.C. Allan, D.A. Reusser, and S. Rumril, 2010: Chapter 6. Impacts of climate change on Oregon's coasts and estuaries. In: *Oregon Climate Assessment Report*. [Dello, K.D. and P.W. Mote(eds.)]. College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, pp. 15-17.

Ruiz-Moreno, D., I.S. Vargas, K.E. Olson, and L.C. Harrington, 2012: Modeling Dynamic Introduction of Chikungunya Virus in the United States. *PLoS Neglected Tropical Diseases,* **6(11)**, e1918.

Russell, R.C., 2009: Mosquito-borne disease and climate change in Australia: time for a reality check. *Australian Journal of Entomology,* **48(1)**, 1-7.

Sahoo, G., S.G. Schladow, J.E. Reuter, and R. Coats, 2011: Effects of climate change on thermal properties of lakes and reservoirs, and possible implications. *Stochastic Environmental Research and Risk Assessment,* **25(4)**, 445-456.

Sakurai, G., T. Iizumi, and M. Yokozawa, 2011: Varying temporal and spatial effects of climate on maize and soybean affect yield prediction. *Climate Research,* **49**, 143-154.

Saldaña-Zorilla, S. and S. Sandberg, 2009: Impact of climate-related disasters on human migration in Mexico: A spatial model. *Climatic Change,* **96**, 97-118.

Saldaña-Zorrilla, S.O., 2008: Stakeholders' views in reducing rural vulnerability to natural disasters in Southern Mexico: Hazard exposure and coping and adaptive capacity. *Global Environmental Change,* **18**, 583-597.

Sallenger, A.H., Jr., K.S. Doran, and P.A. Howd, 2012: Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change,* **2**, 884-888.

Sánchez-Cortés, M.S. and E.L. Chavero, 2011: Indigenous perception of changes in climate variability and its relationship with agriculture in a Zoque community of Chiapas, Mexico. *Climatic Change,* **107(3-4)**, 363-389.

Sandel, B., L. Arge, B. Dalsgaard, R. Davies, K. Gaston, W. Sutherland, and J. Svenning, 2011: The influence of Late Quaternary climate-change velocity on species endemism. *Science,* **334(6056)**, 660-664.

Sander-Regier, R., R. McLeman, M. Brklacich, and M. Woodrow, 2009: Planning for climate change in Canadian rural and resource-based communities. *Environments Journal,* **37(1)**, 35-57.
Sarah, B., 2010: Transforming barriers into enablers of action on climate change: Insights from three municipal case studies in British Columbia, Canada. *Global Environmental Change,* **20(2)**, 287-297.
Satterthwaite, D., S. Huq, H. Reid, M. Pelling, and P. Romero-Lankao, 2007: *Adapting to Climate Change in Urban Areas - The possibilities and constraints in low- and middle-income nations*. In: Human Settlements Discussion Paper Series. International Institute for Environment and Development, London, UK.
Savonis, M.J., V.R. Burkett, and J.R. Potter, 2008: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I*. In: U.S. Climate Change Science Program Synthesis and Assessment Product 4.7. U.S. Climate Change Science Program, Washington DC.
Schaeffer, R., A.S. Szklo, Pereira de Lucena, A. F., Moreira Cesar Borba, B. S., L.P. Pupo Nogueira, F.P. Fleming, A. Troccoli, M. Harrison, and M.S. Boulahya, 2012: Energy sector vulnerability to climate change: A review. *Energy,* **38(1)**, 1-12.
Scheckenberger, R., A. Farrell, and M. Senior, 2009: Economic Assessment of Climate Change Scenarios on Drainage Infrastructure Design.Proceedings of 2009 Annual Conference and Exhibition of the Transportation Association of Canada-Transportation in a Climate of Change, Vancouver, BC, .
Schindler, D.W. and W.F. Donahue, 2006: An impending water crisis in Canada's western prairie provinces. *Proceedings of the National Academy of Sciences,* **103(19)**, 7210-7216.
Schlenker, W., W.M. Hanemann, and A.C. Fisher, 2007: Water Availability, Degree Days, and the Potential Impact of Climate Change on Irrigated Agriculture in California. *Climatic Change,* **81**, 19-38.
Schlenker, W. and M.J. Roberts, 2009: Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences,* **106(37)**, 15594-15598.
Schloss, C.A., T.A. Nuñez, and J.J. Lawler, 2012: Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. *Proceedings of the National Academy of Sciences,* **109(22)**, 8606-8611.
Scholze, M., W. Knorr, N.W. Arnell, and I.C. Prentice, 2006: A climate-change risk analysis for world ecosystems. *Proceedings of the National Academy of Sciences,* **103(35)**, 13116-13120.
Schroth, G., P. Laderach, J. Dempewolf, S.M. Philpott, J. Haggar, H. Eakin, T. Castillejos, J. Garcia Moreno, L. Soto Pinto, R. Hernandez, A. Eitzinger, and J. Ramirez-Villegas, 2009: Towards a climate change adaptation strategy for coffee communities and ecosystems in the Sierra Madre de Chiapas, Mexico. *Mitigation and Adaptation Strategies for Global Change,* **14(7)**, 605-625.
Schwalm, C.R., C.A. Williams, K. Schaefer, D. Baldocchi, T.A. Black, A.H. Goldstein, B.E. Law, W.C. Oechel, K.T.P. U, and R.L. Scott, 2012: Reduction in carbon uptake during turn of htecentury drought in western North America. *Nature Geoscience,* **5**, 551-555.
Scott, D. and G. McBoyle, 2007: Climate change adaptation in the ski industry. *Mitigation and Adaptation Strategies for Global Change,* **12(8)**, 1411-1431.
Scott, D., B. Amelung, S. Becken, J. Ceron, G. Dubois, S. Gössling, P. Peeters, and M. Simpson, 2008a: *Technical Report. In: Climate Change and Tourism: Responding to Global Challenges*. In: Climate Change and Tourism: Responding to Global Challenges. World Tourism Organization and United Nations Environment Programme, Madrid, Spain, pp. 23-250.
Scott, D.J., Dawson, and B. Jones, 2008b: Climate change vulnerability of the US Northeast winter recreation-tourism sector. *Mitigation and Adaptation Strategies for Global Change,* **13**, 577-596.
Scott, D.G., McBoyle, and A. Minogue, 2007: Climate change and quebec's ski industry. *Global Environmental Change,* **17**, 181-190.
Scott, J., 2007: *Agricultural policy and rural poverty in Mexico. Working Paper*. CIDE, Mexico, D.F., .
Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science,* **316(5828)**, 1181-1184.
Seager, R. and G.A. Vecchi, 2010: Greenhouse warming and the 21st century hydroclimate of southwestern North America. *Proceedings of the National Academy of Sciences,* **107(50)**, 21277-21282.
Seager, R., A. Tzanova, and J. Nakamura, 2009: Drought in the Southeastern United States: Causes, Variability over the Last Millennium, and the Potential for Future Hydroclimate Change. *Journal of Climate,* **22**, 5021-5045.
Secretary of the Interior, 2010: *Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources* Washington, D.C., .

Seiler, T., D. Staib, and M. Puttaiah, 2013: *World Insurance in 2012: Progressing on the long and winding road to recovery*. In: Sigma no. 3. Swiss Re, Zurich.
Sharp, J.H., 2010: Estuarine oxygen dynamics: What can we learn about hypoxia from long-time records in the Delaware Estuary? *Limnology and Oceanography,* **55(2)**, 535-548.
Sheffield, J., E.F. Wood, and M.L. Roderick, 2012: Little change in global drought over the past 60 years. *Nature,* **491(7424)**, 435-438.
Shepherd, A., K.M. Gill, and S.B. Rood, 2010: Climate change and future flows of Rocky Mountain rivers: Converging forecasts from empirical trend projection and down-scaled global circulation modelling. *Hydrological Processes,* **24(26)**, 3864-3877.
Shrestha, R.R., M.A. Schnorbus, A.T. Werner, and A.J. Berland, 2012: Modelling spatial and temporal variability of hydrologic impacts of climate change in the Fraser river basin, British Columbia, Canada. *Hydrological Processes,* **26(12)**, 1841-1861.
Sillmann, J., V.V. Kharin, F.W. Zwiers, X. Zhang, and D. Bronaugh, 2013: Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *Journal of Geophysical Research: Atmospheres,* **118**, 2473-2493.
Simmons, K.M. and D. Sutter, 2007: Tornado shelters and the manufactured home parks market. *Natural Hazards,* **43(3)**, 365-378.
Simmons, T.A. (ed.), 1974: *The Damnation of a Dam: The High Ross Dam Controversy*. Diss. Master of Arts, Simon Fraser University, Department of Geography, British Columbia, Canada, .
Sinervo, B., F. Méndez-de-la-Cruz, D.B. Miles, B. Heulin, E. Bastiaans, M. Villagrán-Santa Cruz, R. Lara-Resendiz, N. Martínez-Méndez, M.L. Calderón-Espinosa, R.N. Meza-Lázaro, H. Gadsden, L.J. Avila, M. Morando, I.J. De la Riva, P.V. Sepulveda, C.F.D. Rocha, N. Ibargüengoytía, C.A. Puntriano, M. Massot, V. Lepetz, T.A. Oksanen, D.G. Chapple, A.M. Bauer, W.R. Branch, J. Clobert, and J.W. Sites, 2010: Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches. *Science,* **328(5980)**, 894-899.
Singer, B.D., L.H. Ziska, D.A. Frenz, D.E. Gebhard, and J.G. Straka, 2005: Research note : Increasing Amb a 1 content in common ragweed (Ambrosia artemisiifolia) pollen as a function of rising atmospheric CO2 concentration. *Functional Plant Biology,* **32(7)**, 667-670.
Skinner, W.R., E. Shabbar, M.D. Flannigan, and K. Logan, 2006: Large forest fires in Canada and the relationship to global sea surface temperatures. *Journal of Geophysical Research,* **111(D14106)**.
Skoufias, E., K. Vinha, and H.V. Conroy, 2011: *The Impacts of Climate Variability on Welfare in Rural Mexico*. In: Policy Research Working Paper 5555. The World Bank, Poverty Reduction and Economic Management Network, Poverty Reduction and Equity Unit.
Smith, J.A., M.L. Baeck, G. Villarini, and W.F. Krajewski, 2010: The hydrology and hydrometeorology of flooding in the Delaware River Basin. *Journal of Hydrometeorology,* **11(4)**, 841-859.
Smith, P. and P.J. Gregory, 2013: Climate change and sustainable food production. *Proceedings of the Nutrition Society,* **1(1)**, 1-8.
Smith, J.A., G. Villarini, and M.L. Baeck, 2011: Mixture Distributions and the Hydroclimatology of Extreme Rainfall and Flooding in the Eastern United States. *Journal of Hydrometeorology,* **12**, 294-309.
Smith, J.B., J.M. Vogel, and J.E.I. Cromwell, 2009: An Architecture for Government Action on Adaptation to Climate Change. An Editorial Comment. *Climatic Change,* **95(1-2)**, 53-61.
Smolka, M.O. and A.A. Larangeira, 2008: *Informality and poverty in Latin American urban policies*. In: The New Global Frontier: Urbanization, Poverty and Environment in the 21st Century. Earthscan, London, UK, pp. 99-114.
Sobel, A.H., M. Biasutti, S.J. Camargo, and T.T. Creyts, 2010: Projected Changes in the Physical Climate of the Gulf Coast and Caribbean. *Climatic Change,* **112(3-4)**, 819-845.
Sohngen, B. and R. Sedjo, 2005: Impacts of climate change on forest product markets: Implications for North American producers. *The Forestry Chronicle,* **81(5)**, 669-674.
Solecki, W., 2012: Urban environmental challenges and climate change action in New York City. *Environment and Urbanization,* **24(2)**, 557-573.
Sosa-Rodriguez, F.S., 2010: Impacts of Water-management Decisions on the Survival of a City: From Ancient Tenochtitlan to Modern Mexico City. *Water Resources Development,* **26(4)**, 675-687.
Sosa-Rodriguez, F.S., 2013: From Federal to City Mitigation and Adaptation Strategies: Climate Change Policy in Mexico. *Mitigation and Adaptation Strategies for Global Change,* , 1-28.

Soto-Pinto, L. and M. Anzueto, 2010: Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. *Agroforestry Systems,* **78(1)**, 39-51.
Statistics Canada, 2012: *Table 051- 0001 Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual* Statistics Canada, Canada.
Steiner, A.L., S. Tonse, R.C. Cohen, A.H. Goldstein, and R.a. Harley, 2006: Influence of future climate and emissions on regional air quality in California. *Journal of Geophysical Research,* **111**, 1-22.
Stewart, S.I., V.C. Radeloff, R.B. Hammer, and T.J. Hawbaker, 2006: Defining the Wildland-Urban Interface. *Journal of Forestry,* **105**, 201-207.
Stöckle, C.O., R.L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting, and C. Kruger, 2010: Assessment of climate change impact on Eastern Washington agriculture. *Climatic Change,* **102(1-2)**, 77-102.
Stratos Inc, 2011: *Climate Change and Acid Rock Drainage - Risks for the Canadian Mining Sector*. In: Mine Environment Neutral Drainage (MEND) Program Report 1.67.7. MEND.
Suddick, E.C., K.M. Scow, W.R. Horwath, L.E. Jackson, D.R. Smart, J. Mitchell, and J. Six, 2010: The potential for California agricultural crop soils to reduce greenhouse gas emissions: A holistic evaluation. *Advances in Agronomy,* **107**, 124-162.
Sun, G., S.G. McNulty, J.A. Moore Myers, and E.C. Cohen, 2008: Impacts of multiple stresses on water demand and supply across the southeastern United States. *Journal of the American Water Resources Association,* **44(6)**, 1441-1457.
Swanson, D., J. Hiley, and H.D. Venema, 2007: *Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada: An analysis based on Statistics Canada's Census of Agriculture*. In: Working Paper for the Prairie Climate Resilience Project. International Institute for Sustainable Development, pp. 63.
Sydneysmith, R., M. Andrachuk, B. Smit, and G.K. Hovelsrud, 2010: Vulnerability and Adaptive Capacity in Arctic Communities. In: *Adaptive Capacity and Environmental Governance*. [Armitage, D. and R. Plummer(eds.)]. Springer-Verlag, Berlin, pp. 133-156.
Tabachnick, W.J., 2010: Challenges in predicting climate and environmental effects on vector-borne disease episystems in a changing world. *The Journal of Experimental Biology,* **213(6)**, 946-54.
Tagaris, E., K. Liao, K. Manomaiphiboon, S. He, J. Woo, P. Amar, and A.G. Russell, 2008: The role of climate and emission changes in future air quality over southern Canada and northern Mexico. *Atmospheric Chemistry and Physics,* **8(14)**, 3973-3983.
Tagaris, E., K. Liao, A.J. Delucia, L. Deck, P. Amar, and A.G. Russell, 2009: Potential impact of climate change on air pollution-related human health effects. *Environmental Science & Technology,* **43(13)**, 4979-88.
Tagaris, E., K. Liao, A.J. DeLucia, L. Deck, P. Amar, and A.G. Russell, 2010: Sensitivity of air pollution-induced premature mortality to precursor emissions under the influence of climate change. *International Journal of Environmental Research and Public Health,* **7(5)**, 2222-37.
Tai, A.P.K., L.J. Mickley, and D.J. Jacob, 2010: Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change. *Atmospheric Environment,* **44(32)**, 3976-3984.
Tambo, J.A. and T. Abdoulaye, 2012: Climate change and agricultural technology adoption: the case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change,* **17(3)**, 277-292.
Taner, M.T., J.N. Carleton, and M. Wellman, 2011: Integrated model projections of climate change impacts on a North American lake. *Ecological Modelling,* **222(18)**, 3380-3393.
Tanzeeba, S. and T.Y. Gan, 2012: Potential impact of climate change on the water availability of South Saskatchewan River Basin. *Climatic Change,* **112(2)**, 355-386.
Tao, Z., A. Williams, H. Huang, M. Caughey, and X. Liang, 2007: Sensitivity of U.S. surface ozone to future emissions and climate changes. *Geophysical Research Letters,* **34(8)**, 1-5.
Tarnoczi, T., 2011: Transformative learning and adaptation to climate change in the Canadian Prairies agro-ecosystem. *Mitigation and Adaptation Strategies for Global Change,* **16(4)**, 387-406.
Tarnoczi, T.J. and F. Berkes, 2010: Sources of information for farmers' adaptation practices in Canada's Prairie agro-ecosystem. *Climatic Change,* **98(1)**, 299-305.
Tebaldi, C., B.H. Strauss, and C.E. Zervas, 2012: Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters,* **7(1)**, 014032.
Teixeira, E.I., G. Fischer, H. van Velthuizen, C. Walter, and F. Ewert, 2013: Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology,* **170**, 206-215.

Teranishi, H., T. Katoh, K. Kenda, and S. Hayashi, 2006: Global warming and the earlier start of the Japanese-cedar (Cryptomeria japonica) pollen season in Toyama, Japan. *Aerobiologia,* **22(2)**, 90-94.
Terrier, A., M.P. Girardin, C. Périé, P. Legendre, and Y. Bergeron, 2013: Potential changes in forest composition could reduce impacts of climate change on boreal wildfires. *Ecological Applications,* **23(1)**, 21-35.
The White House, 2009: *Federal Leadership in Environmental, Energy, and Economic Performance - Executive Order 13514* Executive Office of the President, Washington, D.C., .
Theobald, D.M. and W.H. Romme, 2007: Expansion of the US wildland-urban interface. *Landscape and Urban Planning,* **83**, 340-354.
Thomas, M.K., D.F. Charron, D. Waltner-Toews, C.J. Schuster, A.R. Maarouf, and J.D. Holt, 2006: A role of high impact weathe revents in water borne disease outbreaks in Canada. *International Journal of Environmental Health Research,* **16(3)**, 167-180.
Tingley, M.W., W.B. Monahan, S.R. Beissinger, and C. Moritz, 2009: Birds track their Grinnellian niche through a century of climate change. *Proceedings of the National Academy of Sciences,* **106(Supplement 2)**, 19637-19643.
Tong, S.T.Y., Y. Sun, T. Ranatunga, J. He, and Y.J. Yang, 2012: Predicting plausible impacts of sets of climate and land use change scenarios on water resources. *Applied Geography,* **32(2)**, 477-489.
Trainor, S.F., M. Calef, D. Natcher, F.S. Chapin III, A.D. McGuire, O. Huntington, P. Duffy, T.S. Rupp, L. DeWilde, M. Kwart, N. Fresco, and A.L. Lovecraft, 2009: Vulnerability and adaptation to climate-related fire impacts in rural and urban interior Alaska. *Polar Research,* **28**, 100-118.
Transportation Research Board, 2008: *Potential Impacts of Climate Change on U.S. Transportation*. National Research Council of the National Academy of Sciences, Washington, D.C.
Trapp, R.J., N.S. Diffenbaugh, and A. Gluhovsky, 2009: Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations. *Geophysical Research Letters,* **36(1)**, L01703.
Trejo, I., E. Martínez-Meyer, E. Calixto-Pérez, S. Sánchez-Colón, R. Vázquez de La Torre, and L. Villers-Ruiz, 2011: Analysis of the effects of climate change on plant communities and mammals in México. *Atmosfera,* **24(1)**, 1-14.
Tremblay, L., M. Larocque, F. Anctil, and C. Rivard, 2011: Teleconnections and Interannual Variability in Canadian Groundwater Levels. *Journal of Hydrology,* **410**, 178-188.
Trumpickas, J., B.J. Shuter, and C.K. and Minns, 2009: Forecasting impacts of climate change on Great Lakes surface water temperatures. *Journal of Great Lakes Research,* **35(3)**, 454-463.
Tu, J., 2009: Combined impact of climate and land use changes on streamflow and water quality in eastern Massachusetts, USA. *Journal of Hydrology,* **379(3-4)**, 268-283.
Tufts, S., 2010: Tourism, climate change and the missing worker: uneven impacts, institutions and response. In: *What Do We Know? What Do We Need to Know? The State of Canadian Research on Work, Employment and Climate Change*. [Lipsig-Mummé, C. (ed.)]. Work in a Warming World Research Programme, York University, Toronto, pp. 80-108.
U.S. Army Corps of Engineers and Bonneville Power Administration, 2013: *Columbia River Treaty 2014/2024 Review* U.S. Army Corps of Engineers; Bonneville Power Administration, .
U.S. Census Bureau, 2011: *Statistical Abstract of the United States: 2012*. Washington, D.C.
U.S. Department of Agriculture, Economic Research Service, 2012: *U.S. Drought 2012: Farm and Food Impacts* U.S. Department of Agriculture, Economic Research Service, Washington, D.C., .
U.S. Department of Energy, 2013: *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. U.S. Department of Energy, Washington, D.C.
U.S. Environmental Protection Agency, 2004: *National Water Quality Inventory: Report to Congress for the 2004 Reporting Cycle***
**. U.S. Environmental Protection Agency, Washington, D.C., pp. 1-37.
U.S. Environmental Protection Agency, 2008: *Review of the Impacts of Climate Variability and Change on Aeroallergens and Their Associated Effects*. U.S. Environmental Protection Agency, Washington, D.C., pp. 1-125.
U.S. Environmental Protection Agency and Secretaría de Medio Ambiente y Recursos Naturales, 2011: *State of the Border Region Indicators Report 2010*. Secretaría de Medio Ambiente y Recursos Naturales, Tlalpan, Mexico, pp. 1-99.
U.S. Environmental Protection Agency, 2012: *U.S.-Mexico Environmental Program: Border 2012: A Mid-Course Refinement (2008-2012)*. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, National Water Program, 2011: *U.S. EPA National Water Program Strategy: Response to Climate Change 2010 - 2011 National and Regional Highlights of Progress*. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, Office of Atmospheric Programs, 2012: *Climate Change Indicators in the United States, 2012* . U.S Environmental Protection Agency, Washington, D.C., pp. 72-73.

U.S. Forest Service, 2010: *National Roadmap for Responding to Climate Change*. U.S. Department of Agriculture, Forest Service, Washington, D.C., pp. 30.

U.S. Global Change Research Program, 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, New York, USA, pp. 1-192.

U.S. Government Accountability Office, 2007: *Port Risk Management: Additional Federal Guidance Would Aid Ports in Disaster Planning and Recovery*. U.S. Government Accountability Office, Washington, D.C., pp. 1-57.

U.S. Government Accountability Office, 2009: *Climate Change Adaptation: Strategic Federal Planning could help government officials make more informed decisions*. In: Report to the Chairman, Select Committee on Energy Independence and Global Warming, House of Representatives [Government Accounting Office (ed.)]. Congressional Report. Government of United States, Washington, D.C., pp. 1-86.

Urban, D., M.J. Roberts, W. Schlenker, and D.B. Lobell, 2012: Projected temperature changes indicate significant increase in interannual variability of U.S. maize yields. *Climatic Change,* **112**, 525-533.

Ureta, C., E. Martínez-Meyer, H.R. Perales, and E.R. Álvarez-Buylla, 2012: Projecting the effects of climate change on the distribution of maize races and their wild relatives in Mexico. *Global Change Biology,* **18(3)**, 1073-1082.

van Mantgem, P.J., N.L. Stephenson, J.C. Byrne, L.D. Daniels, J.F. Franklin, P.Z. Fulé, M.E. Harmon, A.J. Larson, J.M. Smith, A.H. Taylor, and T.T. Veblen, 2009: Widespread Increase of Tree Mortality Rates in the Western United States. *Science,* **323(5913)**, 521-524.

Vano, J., N. Voisin, L. Cuo, A. Hamlet, M. Elsner, R. Palmer, A. Polebitski, and D. Lettenmaier, 2010a: Climate change impacts on water management in the Puget Sound region, Washington State, USA. *Climatic Change,* **102(1-2)**, 261-286.

Vano, J.A., M.J. Scott, N. Voisin, C.O. Stöckle, A.F. Hamlet, K. Mickelson, and D.P. Lettenmaier, 2010b: Climate change impacts on water management and irrigated agriculture in the Yakima River Basin, Washington, USA. *Climatic Change,* **102(1-2)**, 287-317.

Varady, R. and E. Ward, 2009: Transboundary conservation in context: What drives environmental change? *Conservation of Shared Environments: Learning from the United States and Mexico,* , 9-22.

Vasseur, L. and N. Catto, 2008: Atlantic Canada. In: *From Impacts to Adaptation: Canada in a Changing Climate 2007*. [Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush(eds.)]. Government of Canada, Ottawa, ON, pp. 119-170.

Vasseur, L., 2011: Moving from Research into Action on Issues of ClimateChange for a Canadian Community: Integration ofSciences into Decision Making. *The International Journal of Climate Change: Impacts & Responses,* **2(4)**, 116-126.

Veron, J.E.N., O. Hoegh-Guldberg, T.M. Lenton, J.M. Lough, D.O. Obura, P. Pearce-Kelly, C.R.C. Sheppard, M. Spalding, M.G. Stafford-Smith, and A.D. Rogers, 2009: The coral reef crisis: The critical importance of <350 ppm CO₂. *Marine Pollution Bulletin,* **58(10)**, 1428-1436.

Vespa, J., J. Lewis, and R. Kreider, 2013: *America's Families and Living Arrangements: 2012* U.S. Census Bureau, Washington, D.C., .

Villarini, G., J.A. Smith, F. Serinaldi, J. Bales, P.D. Bates, and W.F. Krajewski, 2009: Flood frequency analysis for nonstationary annual peak records in an urban drainage basin. *Advances in Water Resources,* **32(8)**, 1255-1266.

Villarini, G. and J.A. Smith, 2010: Flood peak distributions for the eastern United States. *Water Resources Research,* **46(6)**.

Villarini, G., J.A. Smith, M.L. Baeck, and W.F. Krajewski, 2011: Examining Flood Frequency Distributions in the Midwest U.S. *Journal of the American Water Resources Association,* **47(3)**, 447-463.

Villeneuve, P.J. and R.T. Burnett, 2003: A time-series study of air pollution, socioeconomic status, and mortality in Vancouver, Canada. *Journal of Exposure Science and Environmental Epidemiology,* **13(6)**, 427-435.

Villeneuve, P.J., M. Doiron, D. Stieb, R. Dales, R.T. Burnett, and R. Dugandzic, 2006: Is outdoor air pollution associated with physician visits for allergic rhinitis among the elderly in Toronto, Canada? *Allergy,* **61(6)**, 750-758.

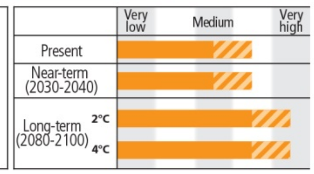
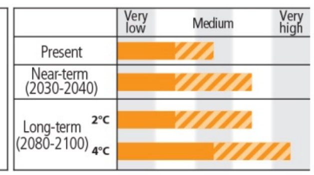
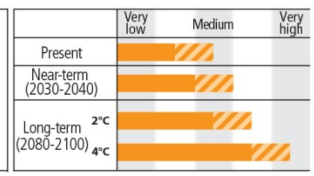
Villers-Ruiz, L. and D. Castañeda-Aguado, In press: *Species and Plant Communities Reorganization in the Trans-Mexican Volcanic Belt under Climate Change Conditions* .

Villers-Ruíz, L. and J. Hernández-Lozano, 2007: Incendios forestales y el fenómeno de El Niño en México.Proceedings of IV Conferencia Internacional sobre Incendios Forestales, May 13-17, 2007, Sevilla, España, pp. 1-10.
von Peter, G., S. von Dahlen, and S. Saxena, 2012: *Unmitigated Disasters? New evidence on the macroeconomic cost of natural catastrophes*. In: BIS Working Papers No 394. Bank for International Settlements.
Vose, J.M., D.L. Peterson, and T. Patel-Weynand, 2012: *Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S*. In: General Technical Report PNW-GTR-870. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 1-265.
Vrolijks, L., A. Spatafpre, and A.S. Mittel, 2011: Comparative research on the adaptation strategies of ten urban climate plans. *In: Resilient Cities: Cities and Adaptation to Climate Change* [Otto-Zimmerman, K. (ed.)]. Proceedings of Proceedings of the Global Forum 2010, Local Sustainability, pp. 193-203.
Walsh, C.J., T.D. Fletcher, and A.R. Ladson, 2005: Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society,* **24(3)**, 690-705.
Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S.-. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, and L.H. Ziska, 2012: *Climate Change and Agriculture in the United States: Effects and Adaptation*. In: USDA Technical Bulletin 1935, Washington, D.C., pp. 1-186.
Wang, X.L., V.R. Swail, and F.W. Zwiers, 2006: Climatology and changes of extratropical cyclone activity: Comparison of ERA-40 with NCEP-NCAR reanalysis for 1958-2001. *Journal of Climate,* **19**, 3145-3166.
Waring, K.M., D.M. Reboletti, L.A. Mork, C. Huang, R.W. Hofstetter, A.M. Garcia, P.Z. Fulé, and T.S. Davis, 2009: Modeling the impacts of two bark beetle species under a warming climate in the southwestern USA: Ecological and economic consequences. *Environmental Management,* **44**, 824-835.
Warren, F.J. and P. Egginton, 2008: Chapter 2: Background Information - Concepts, Overviews and Approaches. In: *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada, Ottawa, pp. 27-56.
Washington State Built Environment: Infrastructure & Communities Topic Advisory Group, 2011: *Interim Recommendations of the Built Environment: Infrastructure & Communities Topic Advisory Group*. In: Washington State Climate Change Response Strategy. Department of Ecology, State of Washington, Olympia, WA, pp. 1-53.
Washington State Human Health and Security Topic Advisory Group, 2011: *Topic Advisory Group (TAG) Report-TAG 2 Human Health and Security*. In: Washington State Climate Change Response Strategy. Department of Ecology, State of Washington, Olympia, WA, pp. 1-17.
Washington State Natural Resources Working Lands and Waters Topic Advisory Group, 2011: *Interim Recommendations of the Natural Resources: Working Lands and Waters Topic Advisory Group*. In: Washington State Climate Change Response Strategy. Department of Ecology, State of Washington, Olympia, WA, pp. 1-44.
Washington State Species, Habitats and Ecosystems Topic Advisory Group, 2011: *Interim Recommendations from Topic Advisory Group 3 Species, Habitats and Ecosystems (TAG3)*. In: Washington State Integrated Climate Change Response Strategy. Department of Ecology, State of Washington, Olympia, WA, pp. 1-95.
Wayne, P., S. Foster, J. Connolly, F. Bazzaz, and P. Epstein, 2002: Production of allergenic pollen by ragweed (Ambrosia artemisiifolia L.) is increased in CO2-enriched atmospheres. *Annals of Allergy, Asthma & Immunology,* **88(3)**, 279-82.
Wehbe, M., H. Eakin, R. Seiler, M. Vinocur, C. Avila, and C. Marutto, 2008: Local perspectives on adaptation to climate change: lessons from Mexico and Argentina. In: *Climate Change and Adaptation*. Earthscan, London, UK, pp. 296-314.
Wehner, M., D.R. Easterling, J.H. Lawrimore, R.R. Heim, R.S. Vose, and B.D. Santer, 2011: Projections of future drought in the continental United States and Mexico. *Journal of Hydrometeorology,* **12(6)**, 1359-1377.
Weisler, R.H., J.G. Barbee, and M.H. Townsend, 2006: Mental health and recovery in the Gulf Coast after Hurricanes Katrina and Rita. *The Journal of the American Medical Association,* **296(5)**, 585-8.

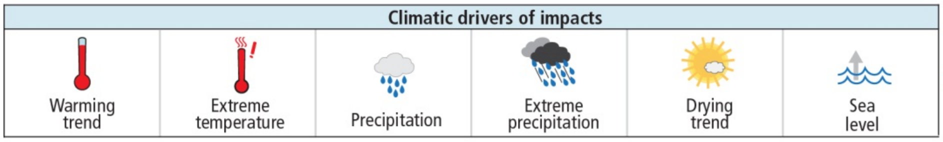
Weiss, J.L., J.T. Overpeck, and B. Strauss, 2011: Implications of Recent Sea Level Rise Science for Low-elevation Areas in Coastal Cities of the Conterminous U.S.A. *Climatic Change,* **105**, 635-645.
Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. *Science,* **313**, 940-943.
Wheaton, E., G. Koshida, B. Bonsal, T. Johnston, W. Richards, and V. Wittrock, 2007: *Agricultural Adaptation to Drought (ADA) in Canada: The Case of 2001 and 2002*. In: SRC Publication No. 11927-1E07. Saskatchewan Research Council, Saskatoon, SK.
Wheaton, E., S. Kulshreshtha, W. Eilers, and V. Wittrock, 2010: Environmental sustainability of agriculture in the context of adapting to a changing climate.Proceedings of OECDINEA-FAO Workshop, Rome, Italy, .
Whitener, L.A. and T. Parker, 2007: Policy Options for a Changing Rural America. *Perspectives on Food and Farm Policy: Rural Development & Energy,* **5**, 58-65.
White-Newsome, J.L., B.N. Sánchez, O. Jolliet, Z. Zhang, E.A. Parker, J. Timothy Dvonch, and M.S. O'Neill, 2012: Climate change and health: Indoor heat exposure in vulnerable populations. *Environmental Research,* **112**, 20-27.
Wiedinmyer, C. and M.D. Hurteau, 2010: Prescribed fire as a means of reducing forest carbon emissions in the Western United States. *Environment, Science and Technology,* **44**, 1926-1932.
Wilbanks, T., D. Bilello, D. Schmalzer, D. Arent, J. Buizer, H. Chum, J. Dell, J. Edmonds, G. Franco, R. Jones, S. Rose, N. . Roy, A. Sanstad, S. Seidel, J. Weyant, and D. Wuebbles, 2012: *Climate Change and Energy Supply and Use: Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment*. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
Wilbanks, T.J., V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott, 2008: *Effects of Climate Change on Energy Production and Use in the United States. Synthesis and Assessment Product 4.5***
**. In: Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, D.C.
Wilder, M., C.A. Scott, N.P. Pablos, R.G. Varady, G.M. Garfin, and J. McEvoy, 2010: Adapting Across Boundaries: Climate Change, Social Learning, and Resilience in the US–Mexico Border Region. *Annals of the Association of American Geographers,* **100(4)**, 917-928.
Wilder, M., G. Garfin, P. Ganster, H. Eakin, P. Romero-Lankao, F. Lara-Valencia, A.A. Cortez-Lara, S. Mumme, C. Neri, and F. Muñoz-Arriola, 2013: Chapter 16: Climate Change and U.S.-Mexico Border Communities. In: *Assessment of Climate Change in the Southwest United States: a Report Prepared for the National Climate Assessment*. [Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy(eds.)]. Island Press, Washington, D.C., .
Williams, A.P., C.D. Allen, C.I. Millar, T.W. Swetnam, J. Michaelson, C.J. Still, and S.W. Leavitt, 2010: Forest responses to increasing aridity and warmth in the southwestern United States. *Proceedings of the National Academy of Sciences,* **107(50)**, 21289-21294.
Williamson, T.B., M. Patriquin, and V. Wittrock, 2008: *Chapter 5: Adaptive capacity deficits of human populations in the Canadian boreal plains ecozone: assessment and issues*. In: Limited Report: Climate Change Adaptive Capacity of Forestry Stakeholders in the Boreal Plains Ecozone. Climate Change Impacts and Adaptation Program Project A1383 [Johnston, M., Williamson, T., Wheaton, E., Wittrock, V., Nelson, H., Hesseln, H., Vandamme, L., Pittman, J. and Lebel, M. (eds.)]. Saskatchewan Research Council, Saskatoon, SK, pp. 46-81.
Williamson, T.B., S.J. Colombo, P.N. Duinker, P.A. Gray, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, and D.L. Spittlehouse, 2009: *Climate change and Canada's forests: from impacts to adaptation*. Edmonton, Canada, Sustainable Forest Management Network and Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre ed., pp. 104.
Wilson, C.O. and Q. Weng, 2011: Simulating the impacts of future land use and climate changes on surface water quality in the Des Plaines River watershed, Chicago Metropolitan Statistical Area, Illinois. *Science of the Total Environment,* **409(20)**, 4387-4405.
Wilson, K., 2009: Climate change and the spread of infectious ideas. *Ecology,* **90(4)**, 901-2.
Winder, R., E.A. Nelson, and T. Beardmore, 2011: Ecological implications for assisted migration in Canadian forests. *The Forestry Chronicle,* **87(6)**, 731-744.
Wittrock, V., S.N. Kulshreshtha, and E. Wheaton, 2011: Canadian prairie rural communities: their vulnerabilities and adaptive capacities to drought. *Mitigation and Adaptation Strategies for Global Change,* **16**, 267-290.

Wolf, J., W.N. Adger, I. Lorenzoni, V. Abrahamson, and R. Raine, 2010: Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two U.K. cities. *Global Environmental Change,* **20**, 44-52.
Wolfe, D.W., L. Ziska, C. Petzoldt, A. Seaman, L. Chase, and K. Hayhoe, 2008: Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change,* **13**, 555-575.
Woodhouse, C., D.M. Meko, G.M. MacDonald, D.W. Stahle, and E.R. Cook, 2010: 1,200-year perspective of 21st century drought in southwestern North America. *Proceedings of the National Academies of Science,* **107**, 21283-21288.
Wootton, J.T., C.A. Pfister, and J.D. Forester, 2008: Dynamic patterns and ecological impacts of declining ocean pH in a high resolution multi-year dataset. *Proceedings of the National Academy of Sciences,* **105**, 18848-18853.
World Bank, 2009: *Globalisation, Wages, and the Quality of Jobs Five Country Studies*. [Robertson, R., Brown, D., Pierre, G. and Sanchez-Puerta, L. (eds.)]. The World Bank, Washington, D.C.
World Bank, 2010: *Natural Hazards, UnNatural Disasters: The Economics of Effective Prevention*. The International Bank for Reconstruction and Development, Washington, D.C.
World Bank, 2011: *Global Economic Prospects: Maintaining Progress Amid Turmoil Volume 3*. The International Bank for Reconstruction and Development / The World Bank, Washington, D.C.
Wright, L., P. Chinowsky, K. Strzepek, R. Jones, R. Streeter, J.B. Smith, J.-. Mayotte, A. Powell, L. Jantarasami, and W. Perkins, 2012: Estimated effects of climate change on flood vulnerability of U.S. Bridges. *Mitigation and Adaptation Strategies for Global Change,* **17(8)**, 939-955.
Wu, S., 2010: Potential impact of climate change on flooding in the upper great miami river watershed, ohio, USA: A simulation-based approach. [Impact potentiel du changement climatique sur les inondations dans le bassin supérieur de la Rivière Great Miami, Ohio, Etats-Unis: Une approche basée sur la simulation]. *Hydrological Sciences Journal,* **55(8)**, 1251-1263.
Wu, S., L.J. Mickley, E.M. Leibensperger, D.J. Jacob, D. Rind, and D.G. Streets, 2008: Effects of 2000â€“2050 global change on ozone air quality in the United States. *Journal of Geophysical Research,* **113**, 1-12.
Yanchuk, A. and G. Allard, 2009: Tree improvement programmes for forest health - can they keep pace with climate changes? *Unasylva,* **60(231-232)**, 50-56.
Yang, L., J.A. Smith, D.B. Wright, M.L. Baeck, G. Villarini, F. Tian, and H. Hu, 2013: Urbanization and Climate Change: An Examination of Nonstationarities in Urban Flooding. *Journal of Hydrometeorology,* **(2013)**.
Yin, J., M.E. Schlesinger, and R.J. Stouffer, 2009: Model projectsion of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience,* **2(4)**, 262-266.
Yin, J.H., 2005: A consistent poleward shift of the storm tracks in simulations of 21st century climate. *Geophysical Research Letters,* **32(18)**, L18701.
Zhang, X.C. and M.A. Nearing, 2005: Impact of climate change on soil erosion, runoff, and wheat productivity in central Oklahoma. *Catena,* **61**, 185-195.
Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. Ann, W. Filley, J. Shropshire, L.B. Ford, C. Hedberg, P. Fleetwood, K.T. Hovanky, and T. Kavanaugh, 2011: Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academies of Science,* **108(10)**, 4248-4251.
Ziska, L.H. and F.A. Caulfield, 2000: Rising CO2 and pollen production of common ragweed (Ambrosia artemisiifolia), a known allergy-inducing species: implications for public health. *Australian Journal of Plant Physiology,* **27**, 893-898.
Ziska, L.H., D.E. Gebhard, D.a. Frenz, S. Faulkner, B.D. Singer, and J.G. Straka, 2003: Cities as harbingers of climate change: Common ragweed, urbanization, and public health. *Journal of Allergy and Clinical Immunology,* **111(2)**, 290-295.

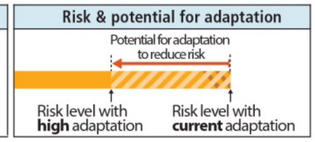
Table 26-1: Key risks from climate change and the potential for risk reduction through adaptation. Key risks are identified based on assessment of the literature and expert judgments made by authors of this chapter, with supporting evaluation of evidence and agreement in the referenced chapter sections. Each key risk is characterized as very low, low, medium, high, or very high. Risk levels are presented for the near-term era of committed climate change (here, for 2030-2040), in which projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. Risk levels are also presented for the longer-term era of climate options (here, for 2080-2100), for global mean temperature increase of 2°C and 4°C above preindustrial levels. For each timeframe, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state. As the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks. Relevant climate variables are indicated by symbols.

Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections	Timeframe / Risk for current and high adaptation
Loss of ecosystem integrity, property loss, human morbidity and mortality due to **wildfires** (*high confidence*)	Some ecosystems are more fire-adapted than others. Forest managers and municipal planners are increasingly incorporating fire protection measures (e.g., prescribed burning, introduction of resilient vegetation). Institutional capacity to support ecosystem adaptation is limited. Adaptation of human settlements is constrained by rapid private property development in high-risk areas and by limited household-level adaptive capacity.		26.4, 26.8.1.2, Box 26-2	
Heat-related human mortality (*high confidence*)	Residential air conditioning (A/C) can effectively reduce risk. However, availability and usage of A/C is often limited among the most vulnerable individuals, and is subject to complete loss during power failures. In addition, there are vulnerable populations including athletes and outdoor workers for whom air conditioning is not available. Community- and household-scale adaptations have the potential to reduce exposure to heat extremes via: family support; heat warnings; cooling centers; greening; high albedo surfaces, etc.		26.6.1.2, 26.8.1.2	
Property and infrastructure damage; supply chain, ecosystem and social system disruption; public health; and water quality impairement from river and coastal **urban floods** (*high confidence*)	Implementing management of urban drainage is expensive and very disruptive to urban areas. There are many no-regret strategies with co-benefits (e.g., less impervious surfaces leading to more groundwater recharge, green infrastructure, and roof-top gardens). Sea level rise increases water elevations in coastal outfalls, which impedes drainage. In many cases, older rainfall design standards are being used which need to be updated to reflect current climate conditions. Significant challenges are also being faced by urban managers due to increased flooding from coastal storms and river-flooding.		26.2.2.2, 26.3.3.2, 26.3.3.3, 26.3.4, 26.4.2, 26.4.2.2, 26.6.1.1, 26.6.1.5, 26.6.2, 26.7, 26.7.1.1, 26.7.5.2.2, 26.8.1.1,26.8.1.2, 26.8.2.1, 26.8.3, 26.8.4.1.2	

Climatic drivers of impacts



Risk & potential for adaptation



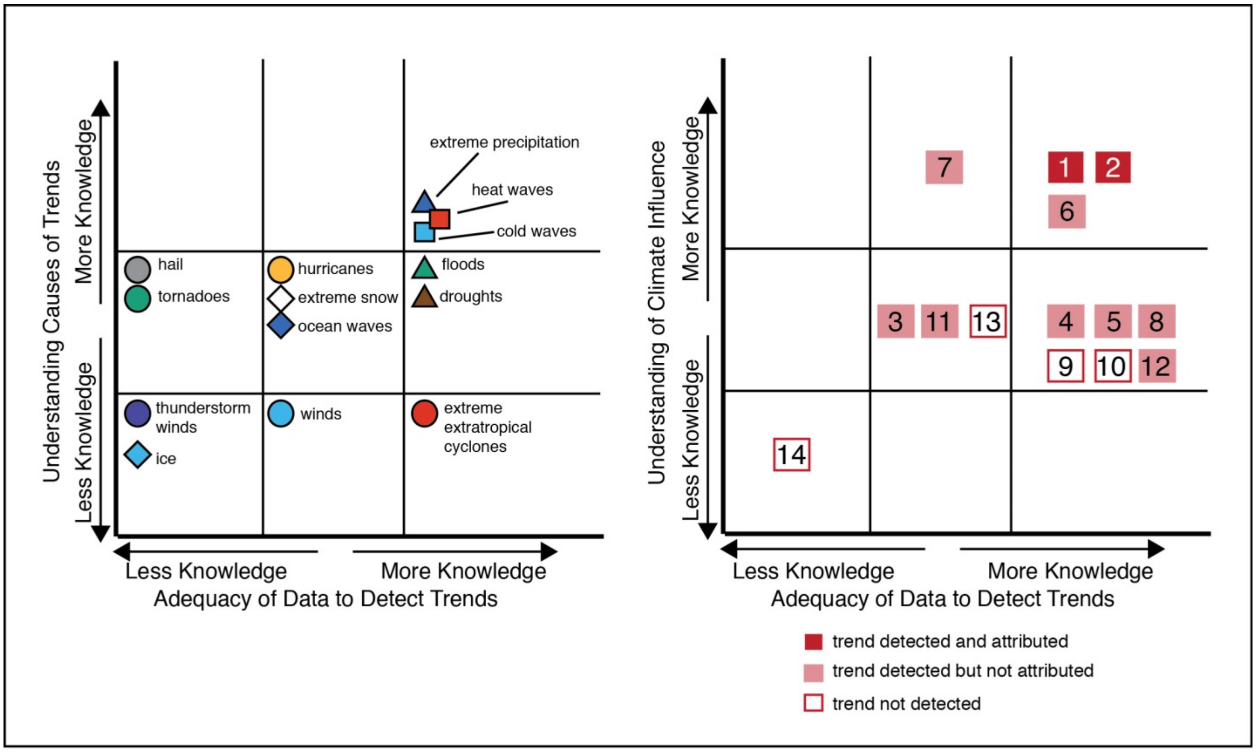


Figure 26-1 Detection and attribution of climate change impacts. Comparisons of the adequacy of currently available data to detect trends and the degree of understanding of causes of those changes in climatic extreme events in the United States (left; Peterson *et al*., 2013) and degree of understanding of the climate influence in key impacts in North America (right). Note that "climate influence" means that the impact has been documented to be sensitive to climate, not that it has been attributed to climate change. Filled boxes indicate that formal detection and attribution to climate change has been performed for the given impact; shaded boxes indicate that a trend has been detected from background variability in the given impact, but formal attribution to climate change has not occurred and the trend could be due to other drivers; and open boxes indicate that a trend has not currently been detected. Key impacts are: 1) earlier peak flow of snowmelt run-off in snow-dominated streams and rivers in western North America [26.3.1], 2) declines in the amount of water stored in spring snowpack in snow-dominated areas of western North America [26.3.1], 3) northward and upward shifts in species' distributions in multiple taxa of terrestrial species, although not all taxa and regions [26.4.1], 4) increases in coastal flooding [26.8.1], 5) increases in wildfire activity, including fire season length and area burned by wildfires in the western United States and boreal Canada [Box 26-2], 6) storm-related disaster losses in the United States (most of the increase in insurance claims paid has been attributed to increasing exposure of people and assets in areas of risk) [26.7.6.1, 26.8.1], 7) increases in bark beetle infestation levels in pine tree species in western North America [26.4.2.1], 8) yield increases due in part to increasing temperatures in Canada and higher precipitation in the US; yield variances attributed to climate variability in Ontario and Quebec; yield losses attributed to climate-related extremes across North America [26.5.1], 9) changes in storm-related mortality in the United States [26.6.1.2], 10) changes in heat-related mortality in the United States [26.6.1.2], 11) increases in tree mortality rates in old-growth forests in the western United States and western Canada from 1960-2007 [26.4.2.1], 12) changes in flooding in some urban areas due to extreme rainfall [26.3.1, 26.8.2.1], 13) increase in water supply shortages due to drought [26.8.1, 26.3], and 14) changes in cold-related heat mortality [26.6.1.2]. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

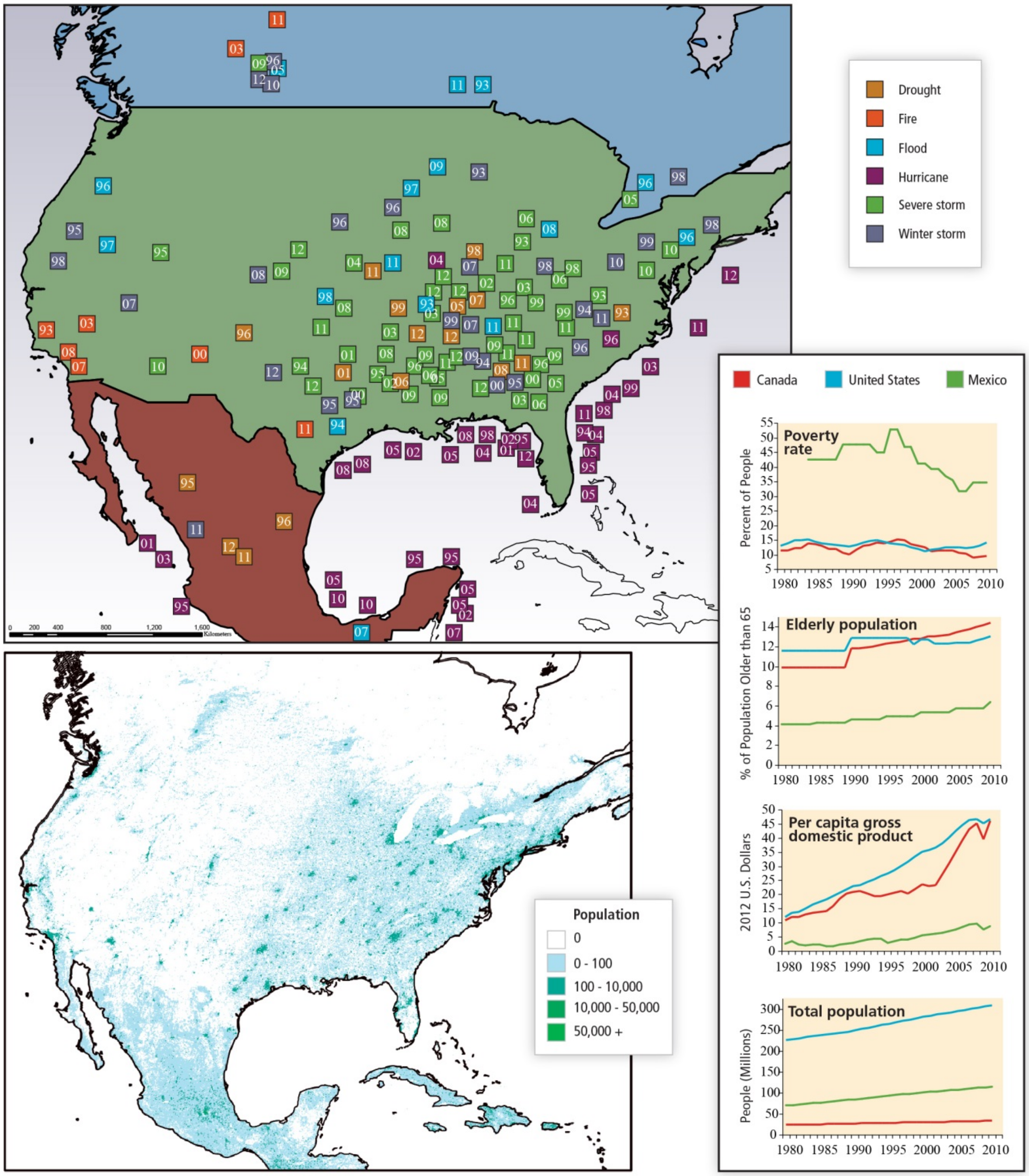

Drought
Fire
Flood
Hurricane
Severe storm
Winter storm
Kilometers
Population
0
0 - 100
100 - 10,000
10,000 - 50,000
50,000 +
Canada
United States
Mexico
Poverty rate
Percent of People
Elderly population
% of Population Older than 65
Per capita gross domestic product
2012 U.S. Dollars
Total population
People (Millions)
1980 1985 1990 1995 2000 2005 2010

Figure 26-2: Extreme events illustrating vulnerabilities for Mexico, the United States, and Canada. This figure offers a graphic illustration of location of extreme events and relevant vulnerability trends. The observed extreme events have not been attributed to anthropogenic climate change, yet they are climate-sensitive sources of impact illustrating vulnerability of exposed systems, particularly if projected future increases in the frequency and/or intensity of such events should materialize. The figure includes:

a) A map (bottom) with population density at 1km resolution highlighting exposure and represented using 2011 Landscan data (Bright *et al.*, 2012).
b) A map (top) with significant weather events taking place during 1993-2012. The map only includes disasters with overall losses of more than $1 billion US dollars in US, or more than $500 million US dollars in Mexico and Canada, adjusted to 2012 values (Source: (NatCatSERVICE, 2010). Hence, it does not include the occurrence of disasters of small and medium impact, and it does not capture the impacts of disasters on populations' livelihoods and wellbeing. Disasters represented by points that are located at the approximate geographic center of affected regions, frequently span more than one subnational jurisdiction (e.g., the 2012 drought affected 12 Mexican states, Annex Table).
c) Four panels (right) with trends in socio-demographic indicators used in the literature to measure vulnerability to hazards (Romero-Lankao *et al.*, 2012): poverty rates, percentage of elderly, GDP per capita and total population (Sources: Comisión Económica para América Latina y el Caribe; U.S. Census Bureau, 2011; Statistics Canada, 2012).

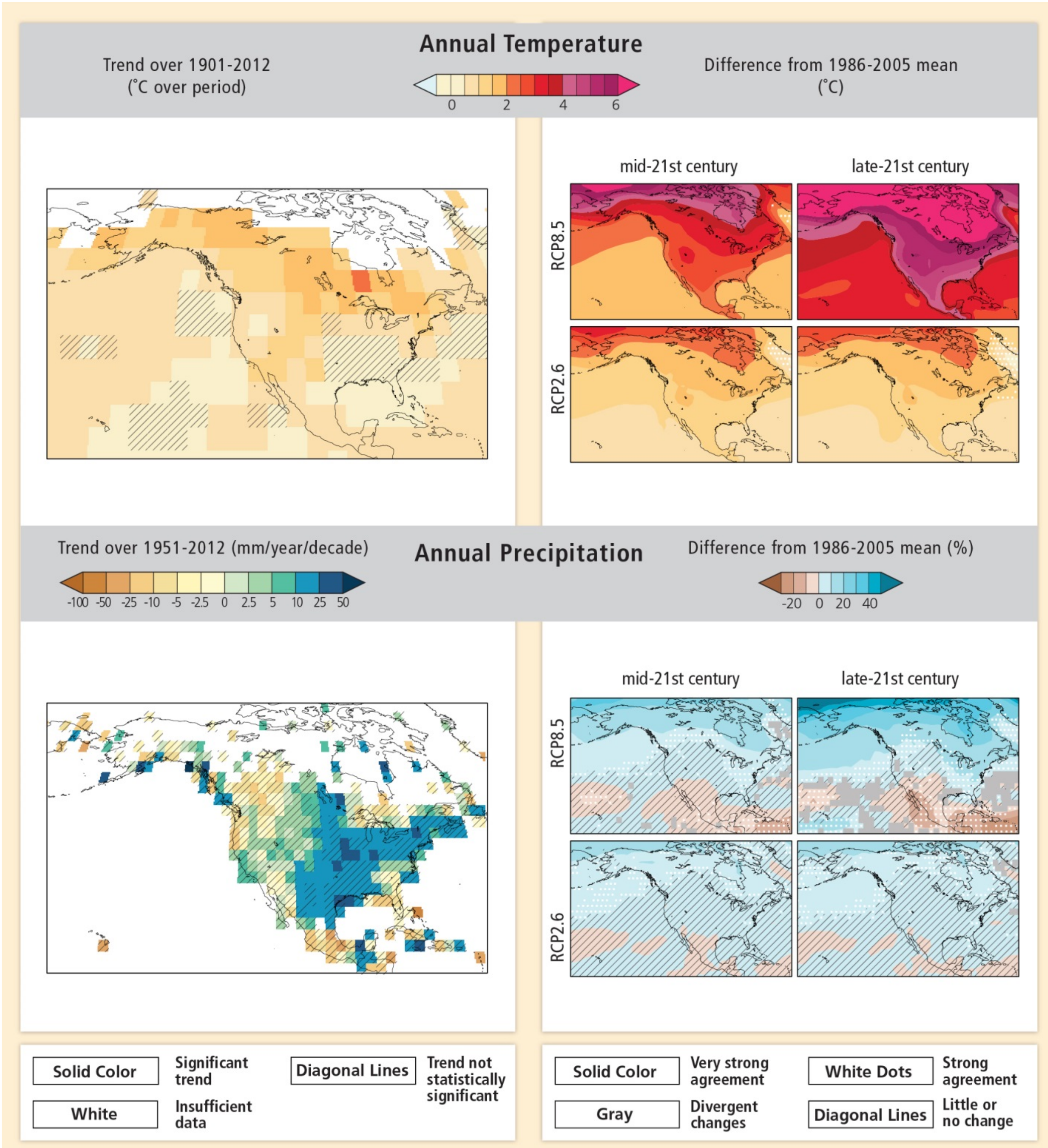


Figure 26-3: Observed and projected Changes in annual temperature and precipitation. (Top panel, left) observed temperature trends from 1901-2012 determined by linear regression [WGI AR5 Figures SPM.1 and 2.21]. (Bottom panel, left) Observed precipitation change from 1951-2010 determined by linear regression. [WGI AR5 Figure SPM.2] For observed temperature and precipitation, trends have been calculated where sufficient data permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level. Diagonal lines indicate areas where change is not significant (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent change in annual mean precipitation for 2046-2065 and 2081-2100 under RCP2.6 and 8.5. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline

variability, and >90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, less than the baseline variability in >66% of models. (There may be significant change at shorter timescales such as seasons, months, or days.). Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See also Annex I of WGI AR5. [Boxes 21-3 and CC-RC]

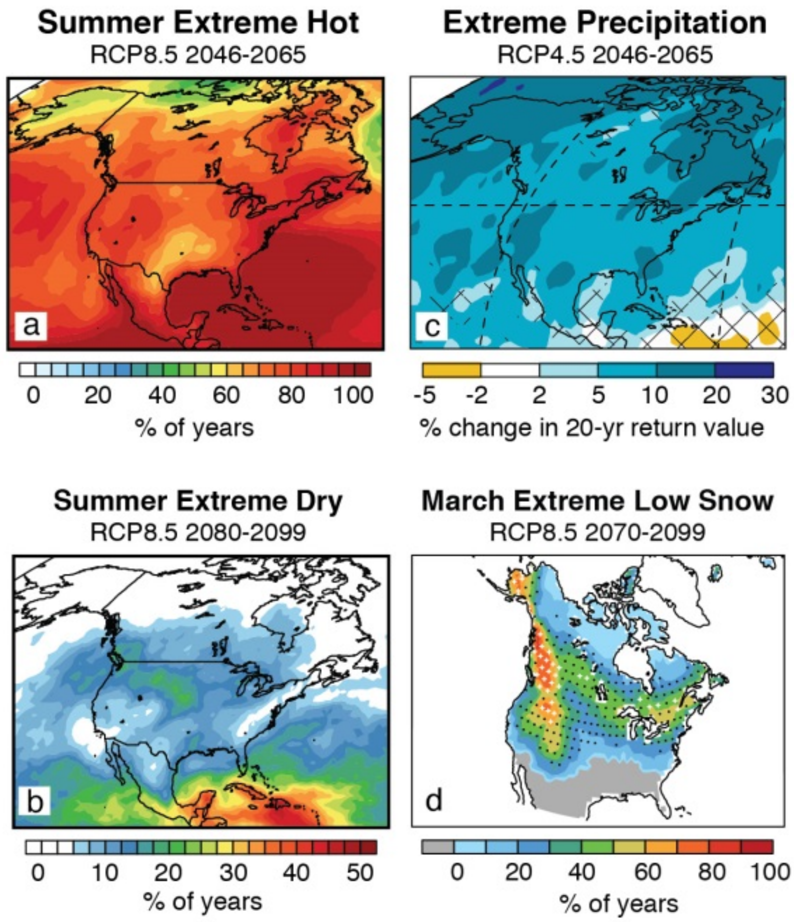


Figure 26-4: Projected changes in extremes in North America. (a) The percentage of years in the 2046–2065 period of RCP8.5 in which the summer temperature is greater than the respective maximum summer temperature of the 1986–2005 baseline period (Diffenbaugh and Giorgi, 2012). (b) The percentage of years in the 2080-2099 period of RCP8.5 in which the summer precipitation is less than the respective minimum summer precipitation of the 1986-2005 baseline period (Diffenbaugh and Giorgi, 2012) (c) The percentage difference in the 20-year return value of annual precipitation extremes between the 2046-2065 period of RCP4.5 and the 1986-2005 baseline period (from (Kharin *et al.*, 2013). The hatching indicates areas where the differences are not significant at the 5% level. (d) The percentage of years in the 2070-2099 period of RCP8.5 in which the March snow water equivalent is less than the respective minimum March snow water equivalent of the 1976–2005 period (Diffenbaugh *et al.*, 2012). The black (white) stippling indicate areas where the multimodel mean exceeds 1.0 (2.0) standard deviations of the multi-model spread. (a-d) The RCPs and time periods are those used in the peer-reviewed studies in which the panels appear. The 2046-2065 period of RCP8.5 and the 2046-2065 period of RCP4.5 exhibit global warming in the range of 2-3˚C above the pre-industrial baseline (WGI Fig. 12.40). The 2080-2099 and 2070-2099 periods of RCP8.5 exhibit global warming in the range of 4-5˚C above the pre-industrial baseline (WGI Fig. 12.40).
[Illustration to be redrawn to conform to IPCC publication specifications.]