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Central and South America

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Executive Summary

Significant trends in precipitation and temperature have been observed in Central America (CA) and South America (SA) (*high confidence*). In addition, changes in climate variability and in extreme events have severely affected the region (*medium confidence*). Increasing trends in annual rainfall in southeastern South America (SESA; 0.6 mm day^{-1} 50 yr^{-1} during 1950–2008) contrast with decreasing trends in CA and central-southern Chile (–1 mm day^{-1} 50 yr^{-1} during 1950–2008). Warming has been detected throughout CA and SA (near 0.7°C to 1°C 40 yr^{-1} since the mid-1970s), except for a cooling off the Chilean coast of about –1 °C 40 yr^{-1}. Increases in temperature extremes have been identified in CA and most of tropical and subtropical SA (*medium confidence*), while more frequent extreme rainfall in SESA has favored the occurrence of landslides and flash floods (*medium confidence*). {27.2.1.1; Table 27-1; Box 27-1}

Climate projections suggest increases in temperature, and increases or decreases in precipitation for CA and SA by 2100 (*medium confidence*). In post-Fourth Assessment Report (AR4) climate projections, derived from dynamic downscaling forced by Coupled Model Intercomparison Project Phase 3 (CMIP3) models for various Special Report on Emission Scenarios (SRES) scenarios, and from different global climate models from the CMIP5 for various Representative Concentration Pathways (RCPs) (4.5 and 8.5), warming varies from +1.6°C to +4.0°C in CA, and +1.7°C to +6.7°C in SA (*medium confidence*). Rainfall changes for CA range between –22 and +7% by 2100, while in SA rainfall varies geographically, most notably showing a reduction of –22% in northeast Brazil, and an increase of +25% in SESA (*low confidence*). By 2100 projections show an increase in dry spells in tropical SA east of the Andes, and in warm days and nights in most of SA (*medium confidence*). {27.2.1.2; Table 27-2}

Changes in streamflow and water availability have been observed and projected to continue in the future in CA and SA, affecting already vulnerable regions (*high confidence*). The Andean cryosphere is retreating, affecting the seasonal distribution of streamflows (*high confidence*). {Table 27-3} Increasing runoffs in the La Plata River basin and decreasing ones in the Central Andes (Chile, Argentina) and in CA in the second half of the 20th century were associated with changes in precipitation (*high confidence*). Risk of water supply shortages will increase owing to precipitation reductions and evapotranspiration increases in semi-arid regions (*high confidence*) {Table 27-4}, thus affecting water supply for cities (*high confidence*) {27.3.1.1, 27.3.5}, hydropower generation (*high confidence*) {27.3.6, 27.6.1}, and agriculture. {27.3.1.1} Current practices to reduce the mismatch between water supply and demand could be used to reduce future vulnerability (*medium confidence*). Ongoing constitutional and legal reforms toward more efficient and effective water resources management and coordination constitute another adaptation strategy (*medium confidence*). {27.3.1.2}

Land use change contributes significantly to environmental degradation, exacerbating the negative impacts of climate change (*high confidence*). Deforestation and land degradation are attributed mainly to increased extensive and intensive agriculture. The agricultural expansion, in some regions associated with increases in precipitation, has affected fragile ecosystems, such as the edges of the Amazon forest and the tropical Andes. Even though deforestation rates in the Amazon have decreased substantially since 2004 to a value of 4,656 km^2 yr^{-1} in 2012, other regions such as the Cerrado still present high levels of deforestation, with average rates as high as 14,179 km^2 yr^{-1} for the period 2002–2008. {27.2.2.1}

Conversion of natural ecosystems is the main cause of biodiversity and ecosystem loss in the region, and is a driver of anthropogenic climate change (*high confidence*). Climate change is expected to increase the rates of species extinction (*medium confidence*). For instance, vertebrate species turnover until 2100 will be as high as 90% in specific areas of CA and the Andes Mountains. In Brazil, distribution of some groups of birds and plants will be dislocated southward, where there are fewer natural habitats remaining. However, CA and SA have still large extensions of natural vegetation cover for which the Amazon is the main example. {27.3.2.1} Ecosystem-based adaptation practices are increasingly common across the region, such as the effective management and establishment of protected areas, conservation agreements, and community management of natural areas. {27.3.2.2}

Socioeconomic conditions have improved since AR4; however, there is still a high and persistent level of poverty in most countries, resulting in high vulnerability and increasing risk to climate variability and change (*high confidence*). Poverty levels in most countries remain high (45% for CA and 30% for SA for year 2010) in spite of the sustained economic growth observed in the last decade. The Human Development Index varies greatly between countries, from Chile and Argentina with the highest values to Guatemala and Nicaragua with the lowest values in 2007. The economic inequality translates into inequality in access to water, sanitation, and adequate housing, particularly for the most vulnerable groups, translating into low adaptive capacities to climate change. {27.2.2.2}

Sea level rise (SLR) and human activities on coastal and marine ecosystems pose threats to fish stocks, corals, mangroves, recreation and tourism, and control of diseases (*high confidence*). SLR varied from 2 to 7 mm yr^{-1} between 1950 and 2008. Frequent coral bleaching events associated with ocean warming and acidification occur in the Mesoamerican Coral Reef. In CA and SA, the main drivers of mangrove loss are deforestation and land conversion to agriculture and shrimp ponds. {27.3.3.1} Brazilian fisheries' co-management (a participatory multi-stakeholder process) is an example of adaptation as it favors a balance between conservation of marine biodiversity, the improvement of livelihoods, and the cultural survival of traditional populations. {27.3.3.2}

Changes in agricultural productivity with consequences for food security associated with climate change are expected to exhibit large spatial variability (*medium confidence*). In SESA, where projections indicate more rainfall, average productivity could be sustained or increased until the mid-century (*medium confidence*; SRES: A2, B2). {Table 27-5} In CA, northeast of Brazil, and parts of the Andean region, increases in temperature and decreases in rainfall could decrease the productivity in the short term (by 2030), threatening the food security of the poorest population (*medium confidence*). {Table 27-5} Considering that SA will be a key food-producing region in the future, one of the challenges will be to increase the food and bioenergy quality and production while maintaining environmental sustainability under climate change. {27.3.4.1} Some adaptation measures include crop, risk, and water use management along with genetic improvement (*high confidence*). {27.3.4.2}

Renewable energy based on biomass has a potential impact on land use change and deforestation and could be affected by climate change (*medium confidence*). Sugarcane and soy are likely to respond positively to CO_2 and temperature changes, even with a decrease in water availability, with an increase in productivity and production (*high confidence*). The expansion of sugarcane, soy, and oil palm may have some effect on land use, leading to deforestation in parts of the Amazon and CA, among other regions, and loss of employment in some countries (*medium confidence*). {27.3.6.1} Advances in second-generation bioethanol from sugarcane and other feedstocks will be important as a measure of mitigation. {27.3.6.2}

Changes in weather and climatic patterns are negatively affecting human health in CA and SA, by increasing morbidity, mortality, and disabilities (*high confidence*), and through the emergence of diseases in previously non-endemic areas (*high confidence*). With *very high confidence,* climate-related drivers are associated with respiratory and cardiovascular diseases, vector- and water-borne diseases (malaria, dengue, yellow fever, leishmaniasis, cholera, and other diarrheal diseases), hantaviruses and rotaviruses, chronic kidney diseases, and psychological trauma. Air pollution is associated with pregnancy-related outcomes and diabetes, among others. {27.3.7.1} Vulnerabilities vary with geography, age, gender, race, ethnicity, and socioeconomic status, and are rising in large cities (*very high confidence*). {27.3.7.2} Climate change will exacerbate current and future risks to health, given the region's population growth rates and vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, pollution, and food production in poor regions (*medium confidence*).

In many CA and SA countries, a first step toward adaptation to future climate changes is to reduce the vulnerability to present climate. Long-term planning and the related human and financial resource needs may be seen as conflicting with the present social deficit in the welfare of the CA and SA population. Various examples demonstrate possible synergies between development, adaptation, and mitigation planning, which can help local communities and governments to allocate efficiently available resources in the design of strategies to reduce vulnerability. However, the generalization of such actions at a continental scale requires that both the CA and SA citizens and governments address the challenge of building a new governance model, where imperative development needs, vulnerability reduction, and adaptation strategies to climate stresses will be truly intertwined. {27.3.4, 27.4-5}

27.1. Introduction

27.1.1. The Central and South America Region

The Central America (CA) and South America (SA) region harbors unique ecosystems and has the highest biodiversity on the planet and a variety of eco-climatic gradients. Unfortunately, this natural wealth is threatened by advancing agricultural frontiers resulting from a rapidly growing agricultural and cattle production (Grau and Aide, 2008). The region experienced a steady economic growth, accelerated urbanization, and important demographic changes in the last decade; poverty and inequality are decreasing continuously, but at a low pace (ECLAC, 2011c). Adaptive capacity is improving in part thanks to poverty alleviation and development initiatives (McGray et al., 2007).

The region has multiple stressors on natural and human systems derived in part from significant land use changes and exacerbated by climate variability/climate change. Climate variability at various time scales has been affecting social and natural systems, and extremes in particular have affected large regions. In Central and South America, 613 climatological and hydro-meteorological extreme events occurred in the period 2000–2013, resulting in 13,883 fatalities, 53.8 million people affected, and economic losses of US$52.3 billion (www.emdat.be). Land is facing increasing pressure from competing uses such as cattle ranching, food production, and bioenergy.

The region is regarded as playing a key role in the future world economy because countries such as Brazil, Chile, Colombia, and Panama, among others, are rapidly developing and becoming economically important in the world scenario. The region is bound to be exposed to the pressure related to increasing land use and industrialization. Therefore, it is expected to have to deal with increasing emission potentials. Thus, science-based decision making is thought to be an important tool to control innovation and development of the countries in the region.

Two other important contrasting features characterize the region: having the biggest tropical forest of the planet on the one side, and possessing the largest potential for agricultural expansion and development during the next decades on the other. This is the case because the large countries of SA, especially, would have a major role in food and bioenergy production in the future, as long as policies toward adaptation to global climate change will be strategically designed. The region is already one of the top producers and user of bioenergy and this experience will serve as an example to other developing regions as well as developed regions.

27.1.2. Summary of the Fourth Assessment Report and IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation Findings

27.1.2.1. Fourth Assessment Report Findings

According to the Working Group II contribution to the Fourth Assessment Report (WGII AR4), Chapter 13 (Latin America), during the last decades of the 20th century, unusual extreme weather events have been severely affecting the Latin America (LA) region, contributing greatly to the strengthening of the vulnerability of human systems to natural disasters. In addition, increases in precipitation were observed in southeastern South America (SESA), northwest Peru, and Ecuador; while decreases were registered in southern Chile, southwest Argentina, southern Peru, and western CA since 1960. Mean warming was near 0.1°C per decade. The rate of sea level rise (SLR) has accelerated over the last 20 years, reaching 2 to 3 mm yr^{-1}. The glacier-retreat trend has intensified, reaching critical conditions in the Andean countries. Rates of deforestation have been continuously increasing, mainly due to agricultural expansion, and land degradation has been intensified for the entire region.

Mean warming for LA at the end of 21st century could reach 1°C to 4°C (SRES B2) or 2°C to 6°C (SRES A2) (*medium confidence*; WGII AR4 Chapter 13, p. 583). Rainfall anomalies (positive or negative) will be larger for the tropical part of LA. The frequency and intensity of weather and climate extremes is *likely* to increase (*medium confidence*).

Future impacts include: "significant species extinctions, mainly in tropical LA" (*high confidence*); "replacement of tropical forest by savannas, and semi-arid vegetation by arid vegetation" (*medium confidence*); "increases in the number of people experiencing water stress" (*medium confidence*); "probable reductions in rice yields and possible increases of soy yield in SESA" (WGII AR4 Chapter 13, p. 583); and "increases in crop pests and diseases" (*medium confidence*; WGII AR4 Chapter 13, p. 607)—with "some coastal areas affected by sea level rise, weather and climatic variability and extremes" (*high confidence*; WGII AR4 Chapter 13, p. 584).

Some countries have made efforts to adapt to climate change and variability, for example, through the conservation of key ecosystems (e.g., biological corridors in Mesoamerica, Amazonia, and Atlantic forest; compensation for ecosystem services in Costa Rica), the use of early warning systems and climate forecast (e.g., fisheries in eastern Pacific, subsistence agriculture in northeast Brazil), and the implementation of disease surveillance systems (e.g., Colombia) (WGII AR4 Chapter 13, p. 591). However, several constraints such as the lack of basic information, observation, and monitoring systems; the lack of capacity-building and appropriate political, institutional, and technological frameworks; low income; and settlements in vulnerable areas outweigh the effectiveness of these efforts.

27.1.2.2. IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation Findings

As reported in Section 3.4 of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; IPCC, 2012b), a changing climate leads to changes in the frequency, intensity, spatial extent, or duration of weather and climate extremes, and can result in unprecedented extremes. Levels of confidence in historical changes depend on the availability of high-quality and homogeneous data and relevant model projections. This has been a major problem in CA and SA, where a lack of long-term homogeneous and continuous climate and hydrological records and of complete studies on trends has not allowed for an identification of trends in extremes, particularly in CA.

Recent observational studies and projections from global and regional models suggest changes in extremes. With *medium confidence*, increases in warm days and decreases in cold days, as well as increases on warm nights and decreases in cold nights, have been identified in CA, northern SA, northeast Brazil (NEB), SESA, and the west coast of SA. In CA, there is *low confidence* that any observed long-term increase in tropical cyclone activity is robust, after accounting for past changes in observing capabilities. In other regions, such as Amazonia (insufficient evidence), inconsistencies among studies and detected trends result in *low confidence* of observed rainfall trends. Although it is *likely* that there has been an anthropogenic influence on extreme temperature in the region, there is *low confidence* in attribution of changes in tropical cyclone activity to anthropogenic influences.

Projections for the end of the 21st century for differing emissions scenarios (SRES A2 and A1B) show that for all CA and SA, models project substantial warming in temperature extremes. It is *likely* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century on the global scale. With *medium confidence*, it is *very likely* that the length, frequency, and/or intensity of heat waves will experience a large increase over most of SA, with a weaker tendency toward increasing in SESA. With *low confidence*, the models also project an increase of the proportion of total rainfall from heavy falls for SESA and the west coast of SA, while for Amazonia and the rest of SA and CA there are not consistent signals of change. In some regions, there is *low confidence* in projections of changes in fluvial floods. Confidence is low owing to limited evidence and because the causes of regional changes are complex. There is *medium confidence* that droughts will intensify along the 21st century in some seasons and areas due to reduced precipitation and/or increased evapotranspiration in Amazonia and NEB.

The character and severity of the impacts from climate extremes depend not only on the extremes themselves but also on exposure and vulnerability. These are influenced by a wide range of factors, including anthropogenic climate change, climate variability, and socioeconomic development.

Table 27-1 | Regional observed changes in temperature, precipitation, and climate extremes in various sectors of Central America (CA) and South America (SA). Additional information on changes in observed extremes can be found in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; Seneviratne et al., 2012) and the IPCC WGI AR5, Sections 2.4–2.6. (CDDs = consecutive dry days; NAMS = North American Monsoon System; PDSI = Palmer Drought Severity Index; SAMS = South American Monsoon System; SD = standard deviation.)

Region	Variable	Reference	Period	Observed changes
Central America and northern South America	Precipitation in NAMS	Englehart and Douglas (2006)	1943–2002	+0.94 mm day^{-1} over 58 years
	Rainfall onset in NAMS	Grantz et al. (2007)	1948–2004	–10 to –20 days over 57 years
	Summertime precipitation in NAMS	Anderson et al. (2010)	1931–2000	+17.6 mm per century
	Rainfall extremes (P95) in NAMS	Cavazos et al. (2008)	1961–1998	+1.3% per decade
	Cold days and nights in CA and northern SA	Donat et al. (2013)	1951–2010	Cold days: –1 day per decade. Cold nights: –2 days per decade
	Warm days and nights in northern SA	Donat et al. (2013)	1951–2010	Warm days: +2 to +4 days per decade. Warm nights: +1 to +3 days per decade
	Heavy precipitation (R10) in northern SA	Donat et al. (2013)	1951–2010	+1 to +2 days per decade
	CDDs in northern SA	Donat et al. (2013)	1951–2010	–2 days per decade
West coast of South America	Sea surface temperature and air temperatures off coast of Peru and Chile (15°S–35°S)	Falvey and Garreaud (2009); Gutiérrez et al. (2011a,b); Kosaka and Xie (2013)	1960–2010	–0.25°C per decade, –0.7°C over 11 years for 2002–2012
	Temperature, precipitation, cloud cover, and number of rainy days since the mid-1970s off the coast of Chile (18°S–30°S)	Schulz et al. (2012)	1920–2009	–1°C over 40 years, –1.6 mm over 40 years, –2 oktas over 40 years, and –0.3 day over 40 years
	Wet days until 1970, increase after that, reduction in the precipitation rate in southern Chile (37°S–43°S)	Quintana and Aceituno (2012)	1900–2007	–0.34% until 1970 and +0.37% after that, –0.12%
	Cold days and nights on all SA coast	Donat et al. (2013)	1951–2010	Cold days: –1 day per decade. Cold nights: –2 days per decade
	Warm nights on all SA coast, warm days in the northern coast of SA, warm days off the coast of Chile	Donat et al. (2013)	1951–2010	Warm nights: –1 day per decade. Warm days: +3 days per decade. Warm days: –1 day per decade
	Warm nights on the coast of Chile	Dufek et al. (2008)	1961–1990	+5% to +9% over 31 years
	Dryness as estimated by the PDSI for most of the west coast of SA (Chile, Ecuador, northern Chile)	Dai (2011)	1950–2008	–2 to –4 over 50 years
	Heavy precipitation (R95) in northern and central Chile	Dufek et al. (2008)	1961–1990	–45 to –105 mm over 31 years
	Temperature and extreme precipitation in southern Chile	Vicuña et al. (2013)	1976–2008	Increase in annual maximum temperature from +0.5°C to +1.1°C per decade; change in number of days with intense rainfall events from –2.7 to +4.2 days per decade.

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Table 27-1 (continued)

Region	Variable	Reference	Period	Observed changes
Southeastern South America	Mean annual air temperature in southern Brazil	Sansigolo and Kayano (2010)	1913–2006	+0.5°C to +0.6°C per decade
	Frequency of cold days and nights, warm days in Argentina and Uruguay	Rusticucci and Renom (2008)	1935–2002	–1.2% per decade, –1% per decade, +0.2% per decade
	Highest annual maximum temperature, lowest annual minimum air temperature in Argentina and Uruguay	Rusticucci and Tencer (2008)	1956–2003	+0.8°C over 47 years, +0.6°C over 47 years
	Warm nights in Argentina and Uruguay and southern Brazil	Rusticucci (2012)	1960–2009	+10–20% over 41 years
	Warm nights in most of the region	Dufek et al. (2008)	1961–1990	+7% to +9% over 31 years
	Cold nights in most of the region	Dufek et al. (2008)	1961–1990	–5% to –9% over 31 years
	Warm days and nights in most of the region	Donat et al. (2013)	1951–2010	Warm nights: +3 days per decade. Warm days: +4 days per decade
	Cold days and nights in most of the region	Donat et al. (2013)	1951–2010	Cold nights: –3 days per decade. Cold days: –3 days per decade
	CDDs in the La Plata Basin countries (Argentina, Bolivia, and Paraguay) and decrease of CDDs in SA south of 30°S	Dufek et al. (2008)	1961–1990	+15 to +21 days over 31 years, –21 to –27 days over 31 years
	Number of dry months during the warm season (October–March) in the Pampas region between 25°S and 40°S	Barrucand et al. (2007)	1904–2000	From 2–3 months in 1904–1920 to 1–2 months in 1980–2000
	Moister conditions as estimated by the PDSI in most of southeastern SA	Dai (2011)	1950–2008	0–4 PDSI over 50 years
	Rainfall trends in the Paraná River Basin	Dai et al. (2009)	1948–2008	+1.5 mm day^{-1} over 50 years
	Number of days with precipitation above 10 mm (R10) in most of the region	Donat et al. (2013)	1951–2010	+2 days per decade
	Heavy precipitation (R95) in most of the region	Donat et al. (2013)	1951–1910	+1% per decade and –4 days per decade
	Heavy precipitation (R95) in most of the region	Dufek et al. (2008)	1961–1990	+45 to +135 mm over 31 years
	Heavy precipitation (R95) in the state of São Paulo	Dufek and Ambrizzi (2008)	1950–1999	+50 to +75 mm over 40 years
	CDDs in the state of São Paulo	Dufek and Ambrizzi (2008)	1950–1990	–25 to –50 days over 40 years
	Lightning activity varies significantly with change in temperature in the state of São Paulo	Pinto and Pinto (2008); Pinto et al. (2013)	1951–2006	+40% per 1°C for daily and monthly time scales and approximately +30% per 1°C for decadal time scale
	Number of days with rainfall above 20 mm in the city of São Paulo	Silva Dias et al. (2012); Marengo et al. (2013)	2005–2011	+5 to +8 days over 11 years
	Excess rainfall events duration after 1950	Krepper and Zucarelli (2010)	1901–2003	+21 months over 53 years
	Dry events and events of extreme dryness from 1972 to 1996	Vargas et al. (2011)	1972–1996	–29 days over 24 years
	Number of dry days in Argentina	Rivera et al. (2013)	1960–2005	–2 to –4 days per decade
	Extreme daily rainfall in La Plata Basin	Penalba and Robledo (2010)	1950–2000	+33% to +60% increase in spring, summer, and autumn, –10% to –25% decrease in winter
	Frequency of heavy rainfall in Argentina, southern Brazil, and Uruguay	Re and Barros (2009)	1959–2002	+50 to +150 mm over 43 years
	Annual precipitation in the La Plata Basin	Doyle and Barros (2011); Doyle et al. (2012)	1960–2005	+5 mm $year^{-1}$

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27.2. Major Recent Changes and Projections in the Region

27.2.1. Climatic Stressors

27.2.1.1. Climate Trends, Long-Term Changes in Variability, and Extremes

In CA and SA, decadal variability and changes in extremes have been affecting large sectors of the population, especially those more vulnerable and exposed to climate hazards. Observed changes in some regions have been attributed to natural climate variability, while in others they have been attributed to land use change (e.g., increased urbanization), meaning that land use change is a result of anthropogenic drivers. Table 27-1 summarizes the observed trends in the region's climate.

Since around 1950, in CA and the North American Monsoon System (NAMS), rainfall has been starting increasingly later and has become more irregular in space and time, while rainfall has been increasing and the intensity of rainfall has been increasing during the onset season (see references in Table 27-1). Arias et al. (2012) relate those changes to decadal rainfall variations in NAMS.

The west coast of SA experienced a prominent but localized coastal cooling of about 1°C during the past 30 to 50 years extending from central Peru down to central Chile. This occurs in connection with an increased upwelling of coastal waters favored by the more intense trade winds (Falvey and Garreaud, 2009; Narayan et al., 2010; Gutiérrez et al., 2011a,b; Schulz et al., 2012; Kosaka and Xie, 2013). In the extremely arid northern coast of Chile, rainfall, temperature, and cloudiness show strong interannual and decadal variability, and since the mid-1970s,

Table 27-1 (continued)

Region	Variable	Reference	Period	Observed changes
Andes	Mean maximum temperature along the Andes, and increase in the number of frost days	Marengo et al. (2011b)	1921–2010	+0.10°C to +0.12°C per decade in 1921–2010, and +0.23–0.24°C per decade during 1976–2010; +8 days per decade during 1996–2002
	Air temperature and changes in precipitation in northern Andes (Colombia, Ecuador)	Villacís (2008)	1961–1990	+0.1°C to +0.22°C per decade, –4% to +4% per decade
	Temperature and precipitation in northern and central Andes of Peru	SENAMHI (2005, 2007, 2009a,c,d)	1963–2006	+0.2°C to +0.45°C per decade, –20% to –30% over 40 years
	Temperature and precipitation in the southern Andes of Peru	SENAMHI (2007, 2009a,b,c,d); Marengo et al. (2011b)	1964–2006	+0.2°C to +0.6°C per decade, –11 to +2 mm per decade
	Air temperature and rainfall over Argentinean and Chilean Andes and Patagonia	Masiokas et al. (2008); Falvey and Garreaud (2009)	1950–1990	+0.2°C to +0.45°C per decade, –10% to –12% per decade
	Number of days with rainfall above 10 mm (R10)	Donat et al. (2013)	1950–2010	–3 days per decade
	Dryness in the Andes between 35.65°S and 39.9°S using the PDSI	Christie et al. (2011)	1950–2003	–7 PDSI over 53 years
	Rainfall decrease in the Mantaro Valley, central Andes of Peru	SENAMHI (2009c)	1970–2005	–44 mm per decade
	Air temperature in Colombian Andes	Poveda and Pineda (2009)	1959–2007	+1°C over 20 years
Amazon region	Decadal variability of rainfall in northern and southern Amazonia	Marengo et al. (2009b); Satyamurty et al. (2010)	1920–2008	–3 SDs over 30 years in northern Amazonia and +4 SDs over 30 years in southern Amazonia since the mid-1970s
	Rainfall in all the region	Espinoza et al. (2009a,b)	1975–2003	–0.32% over 28 years
	Onset of the rainy season in southern Amazonia	Butt et al. (2011); Marengo et al. (2011b)	1950–2010	–1 month since 1976–2010
	Precipitation in the SAMS core region	Wang et al. (2012)	1979–2008	+2 mm day^{-1} per decade
	Onset becomes steadily earlier from 1948 to early 1970s, demise dates have remained later, and SAMS duration was longer after 1972	Carvalho et al. (2011)	1948–2008	SAMS from 170 days (1948–1972) to 195 days (1972–1982)
	Spatially varying trends of heavy precipitation (R95), increase in many areas and insufficient evidence in others	Marengo et al. (2009b)	1961–1990	+100 mm over 31 years in western and extreme eastern Amazonia
	Spatially varying trends in dry spells (CDDs), increase in many areas and decrease in others	Marengo et al. (2009b, 2010)	1961–1990	+15 mm over 31 years in western Amazonia, –20 mm in southern Amazonia
	Rainfall in most of Amazonia and in western Amazonia	Dai et al. (2009); Dai (2011)	1948–2008	+1 mm day^{-1} over 50 years, –1.5 mm day^{-1} over 50 years
	Dryness as estimated by the PDSI in southern Amazonia and moister conditions in western Amazonia	Dai (2011)	1950–2008	–2 to –4 over 50 years, +2 to +4 over 50 years
	Seasonal mean convection and cloudiness	Arias et al. (2011)	1984–2007	+30 W m^{-2} over 23 years, –8% over 23 years
	Onset of rainy season in southern Amazonia due to land use change	Butt et al. (2011)	1970–2010	–0.6 days over 30 years
	Precipitation in the region	Gloor et al. (2013)	1990–2010	–20 mm over 21 years
Northeastern Brazil	Rainfall trends in interior northeastern Brazil and in northern northeastern Brazil	Dai et al. (2009); Dai (2011)	1948–2008	–0.3 mm day^{-1} over 50 years, +1.5 mm day^{-1} over 50 years
	Heavy precipitation (R95) in some areas, and in southern northeastern Brazil	Silva and Azevedo (2008)	1970–2006	–2 mm over 24 years to +6 mm over 24 years
	CDDs in most of southern northeastern Brazil	Silva and Azevedo (2008)	1970–2006	–0.99 day over 24 years
	Total annual precipitation in northern northeastern Brazil	Santos and Brito (2007)	1970–2006	+1 to +4 mm year^{-1} over 24 years
	Spatially varying trends in heavy precipitation (R95) in northern northeastern Brazil	Santos and Brito (2007)	1970–2006	–0.1 to +5 mm year^{-1} over 24 years
	Spatially varying trends in heavy precipitation (R95) and CDDs in northern northeastern Brazil	Santos et al. (2009)	1935–2006	–0.4 to +2.5 mm year^{-1} over 69 years, –1.5 to +1.5 days year^{-1} over 69 years
	Dryness in southern northeastern Brazil as estimated by the PDSI, and northern northeastern Brazil	Dai (2011)	1950–2008	–2 to –4 over 50 years, 0 to +1 over 50 years

the minimum daily temperature, cloudiness, and precipitation have decreased. In central Chile, a negative precipitation trend was observed over the period 1935–1976, and an increase after 1976, while further south, the negative trend in rainfall that prevailed since the 1950s has intensified by the end of the 20th century (Quintana and Aceituno, 2012). To the east of the Andes, NEB exhibits large interannual rainfall variability, with a slight decrease since the 1970s (Marengo et al. 2013a). Droughts in this region (e.g., 1983, 1987, 1998) have been associated with El Niño and/or a warmer Tropical North Atlantic Ocean. However, not all El Niño years result in drought in NEB, as the 2012–2013 drought occurred during La Niña (Marengo et al., 2013a).

In the La Plata Basin in SESA, various studies have documented interannual and decadal scale circulation changes that have led to decreases in the

Box 27-1 | Extreme Events, Climate Change Perceptions, and Adaptive Capacity in Central America

Central America (CA) has traditionally been characterized as a region with high exposure to geo-climatic hazards derived from its location and topography and with high vulnerability of its human settlements (ECLAC, 2010c). It has also been identified as the most responsive tropical region to climate change (Giorgi, 2006). Evidence for this has been accumulating particularly in the last 30 years, with a steady increase in extreme events including storms, floods, and droughts. In the period 2000–2009, 39 hurricanes occurred in the Caribbean basin compared to 15 and 9 in the 1980s and 1990s, respectively (UNEP and ECLAC, 2010). The impacts of these events on the population and the economy of the region have been tremendous: the economic loss derived from 11 recent hydrometereological events evaluated amounted to US$13.64 billion and the number of people impacted peaked with Hurricane Mitch in 1998, with more than 600,000 persons affected (ECLAC, 2010c). A high percentage of the population in CA live on or near highly unstable steep terrain with sandy, volcanic soils prone to mudslides, which are the main cause of casualties and destruction (Restrepo and Alvarez, 2006).

The increased climatic variability in the past decade certainly changed the perception of people in the region with respect to climate change. In a survey to small farmers in 2003, Tucker et al. (2010) found that only 25% of respondents included climate events as a major concern. A subsequent survey in 2007 (Eakin et al., 2013) found that more than 50% of respondents cited drought conditions and torrential rains as their greatest concern. Interestingly, there was no consensus on the direction in climate change pattern: The majority of households in Honduras reported an increase in the frequency of droughts but in Costa Rica and Guatemala a decrease or no trend at all was reported. A similar discrepancy in answers was reported with the issue of increased rainfall. But there was general agreement in all countries that rainfall patterns were more variable, resulting in higher difficulty in recognizing the start of the rainy season.

The high levels of risk to disasters in CA are the result of high exposure to hazards and the high vulnerability of the population and its livelihoods derived from elevated levels of poverty and social exclusion (Programa Estado de la Nación-Región, 2011). Disaster management in the region has focused on improving early warning systems and emergency response for specific extreme events (Saldaña-Zorrilla, 2008) but little attention has been paid to strengthening existing social capital in the form of local organizations and cooperatives. These associations can be central in increasing adaptive capacity through increased access to financial instruments and strategic information on global markets and climate (Eakin et al., 2011). There is a need to increase the communication of the knowledge from local communities involved in processes of autonomous adaptation to policymakers responsible for strengthening the adaptive capacities in CA (Castellanos et al., 2013).

frequency of cold nights in austral summer, as well as to increases in warm nights and minimum temperatures during the last 40 years. Simultaneously, a reduction in the number of dry months in the warm season is found since the mid-1970s, while heavy rain frequency is increasing in SESA (references in Table 27-1). In SESA, increases in precipitation are responsible for changes in soil moisture (Collini et al., 2008; Saulo et al., 2010), and although feedback mechanisms are present at all scales, the effect on atmospheric circulation is detected at large scales. Moreover, land use change studies in the Brazilian southern Amazonia for the last decades showed that the impact on the hydrological response is time lagged at larger scales (Rodriguez, D.A. et al., 2010).

In the central Andes, in the Mantaro Valley (Peru), precipitation shows a strong negative trend, while warming is also detected (SENAMHI, 2007). In the southern Andes of Peru air temperatures have increased during 1964–2006, but no clear signal on precipitation changes has been detected (Marengo et al., 2009a). In the northern Andes (Colombia, Ecuador), changes in temperature and rainfall in 1961–1990 have been identified by Villacís (2008). In the Patagonia region, Masiokas et al. (2008) have identified an increase of temperature together with precipitation reductions during 1912–2002. Vuille et al. (2008a) found that climate in the tropical Andes has changed significantly over the past 50 to 60 years. Temperature in the Andes has increased by approximately 0.1°C per decade, with only 2 of the last 20 years being below the 1961–1990 average. Precipitation has slightly increased in the second half of the 20th century in the inner tropics and decreased in the outer tropics. The general pattern of moistening in the inner tropics and drying in the subtropical Andes is dynamically consistent with observed changes in the large-scale circulation, suggesting a strengthening of the tropical atmospheric circulation. Moreover, a positive significant trend in mean temperature of 0.09°C per decade during 1965–2007 has been detected over the Peruvian Andes by Lavado et al. (2012).

For the Amazon basin, Marengo (2004) and Satyamurty et al. (2010) concluded that no systematic unidirectional long-term trends toward drier or wetter conditions in both the northern and southern Amazon have been identified since the 1920s. Rainfall fluctuations are more characterized by interannual scales linked to El Niño-Southern Oscillation (ENSO) or decadal variability. Analyzing a narrower time period, Espinoza et al. (2009a,b) found that mean rainfall in the Amazon basin for 1964–2003 has decreased, with stronger amplitude after 1982, especially in the Peruvian western Amazonia (Lavado et al., 2012), consistent with reductions in convection and cloudiness in the same region (Arias et al., 2011). Recent studies by Donat et al. (2013) suggest that heavy rains are increasing in frequency in Amazonia. Regarding seasonal extremes in the Amazon region, two major droughts and three floods have affected the region from 2005 to 2012, although these events have been related to natural climate variability rather than to deforestation (Marengo et al., 2008, 2012, 2013a; Espinoza et al., 2011, 2012, 2013; Lewis et al., 2011; Satyamurty et al., 2013).

On the impacts of land use changes on changes in the climate and hydrology of Amazonia, Zhang et al. (2009) suggest that biomass-burning aerosols can work against the seasonal monsoon circulation transition, and thus reinforce the dry season rainfall pattern for southern Amazonia,

Table 27-2 | Regional projected changes in temperature, precipitation, and climate extremes in different sectors of Central America (CA) and South America (SA). Various studies used A2 and B2 scenarios from Coupled Model Intercomparison Project Phase 3 (CMIP3) and various Representative Concentration Pathway (RCP) scenarios for CMIP5, and different time slices from 2010 to 2100. To make results comparable, the CMIP3 and CMIP5 at the time slice ending in 2100 are included. Additional information on changes in projected extremes can be found in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; see IPCC, 2012), and in IPCC WGI AR5 Sections 9.5, 9.6, 14.2, and 14.7. (CDDs = consecutive dry days.)

Region	Variable	Reference	Models and scenarios	Projected changes
Central America and northern South America	Leaf Area Index, evapotranspiration by 2070–2099 in CA	Imbach et al. (2012)	23 CMIP3 models, A2	Evapotranspiration: +20%; Leaf Area Index: –20% + 0.94 mm/day/58 years
	Air temperature by 2075 and 2100 in CA	Aguilar et al. (2009)	9 CMIP3 models, A2	+2.2°C by 2075; +3.3°C by 2100
	Rainfall in CA and Venezuela, air temperature in the region	Kitoh et al. (2011); Hall et al. (2013)	20 km MRI-AGCM3.1S model, A1B	Rainfall decrease/increase of about –10%/+10% by 2079. Temperature increases of about +2.5°C to +3.5°C by 2079
	Precipitation and evaporation in most of the region. Soil moisture in most land areas in all seasons	Nakaegawa et al. (2013b)	20 km MRI-AGCM3.1S model, A1B	Precipitation decrease of about –5 mm day^{-1}, evaporation increase of about +3 to +5 mm day^{-1}; soil moisture to decrease by –5 mm day^{-1}
	Rainfall in Nicaragua, Honduras, northern Colombia, and northern Venezuela; rainfall in Costa Rica and Panama. Temperature in all regions by 2071–2100	Campbell et al. (2011)	PRECIS forced with HadAM3, A2	Rainfall: –25% to –50%, and +25% to +50%; temperature: +3°C to +6°C
	Precipitation and temperature in northern SA, decrease in interior Venezuela, temperature increases by 2071–2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Increases by +30% to +50%; reductions by –10% to –20%; temperature: +4°C to +5°C
	Precipitation and temperature by 2100 in CA	Karmalkar et al. (2011)	PRECIS forced with HadAM3, A2	Precipitation: –24% to –48%; temperature: +4°C to +5°C
	Warm nights, CDDs, and heavy precipitation in Venezuela by 2100	Marengo et al. (2009a, 2010)	PRECIS forced with HadAM3, A2	Increase of +12% to +18%, +15 to +25 days, and reduction of 75 to 105 days
	Air temperature and precipitation in CA by 2100	Giorgi and Diffenbaugh (2008)	23 CMIP3 models, A1B	Increase of +3°C to +5°C; reduction of –10% to –30%
	CDDs and heavy precipitation by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Increase of +5 days, increase of +2% to +8%
	Rainfall over Panama by 2099	Fábrega et al. (2013)	20 km MRI-AGCM3.1S model, A1B	Increase of +5%
West coast of South America	Precipitation, runoff, and temperature at the Limari river basin in semi-arid Chile by 2100	Vicuña et al. (2011)	PRECIS forced with HadAM3, A2	Precipitation: –15% to –25%; runoff: –6% to –27%; temperature: +3°C to +4°C
	Air temperature and surface winds in west coast of SA (Chile) by 2100	Garreaud and Falvey (2009)	15 CMIP3 models, PRECIS forced with HadAM3, A2	Temperature: +1°C; coastal winds: +1.5 m s^{-1}
	Precipitation in the bands 5°N–10°S, 25°S–30°S, 10°S–25°S, and 30°S–50°S; temperature increase by 2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Increases of 30–40%; increases of 3°C to 5°C
	Warm nights, CDDs, and heavy precipitation in 5°N–5°S by 2100	Marengo et al. (2009a, 2010)	PRECIS forced with HadAM3, A2	Increase of +3% to +18%, reduction of –5 to –8 days, increase of +75 to +105 days
	Air temperature, increase in precipitation between 0° and 10°S, and between 20°S and 40°S by 2100	Giorgi and Diffenbaugh (2008)	23 CMIP3 models, A1B	Increase of +2°C to +3°C; increase of 10%, reduction of –10% to –30%
	CDDs between 5°N and 10°S and south of 30°S; heavy precipitation between 5°S and 20°S and south of 20°S by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Increase of 10 days and between +2% and +10%
	Precipitation between 15°S and 35°S and south of 40°S; temperature by 2100	Nuñez et al. (2009)	MM5 forced with HadAM3, A2	Precipitation: –2 mm day^{-1}; +2 mm day^{-1}; temperature: +2.5°C
	Precipitation in Panama and Venezuela by 2099	Sörensson et al. (2010)	RCA forced with ECHAM5–MPI OM model, A1B	Precipitation: –1 to –3 mm day^{-1}

Continued next page →

Table 27-2 (continued)

Region	Variable	Reference	Models and scenarios	Projected changes
Southeastern South America	Precipitation and runoff, and air temperature by 2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Precipitation: +20% to +30%; runoff: +10% to +20%; air temperature: +2.5°C to +3.5°C
	Precipitation and temperature in the La Plata basin by 2050	Cabré et al. (2010)	MM5 forced with HadAM3, A2	Precipitation: +0.5 to 1.5 mm day^{-1}; temperature: +1.5°C to 2.5°C
	Warm nights, CDDs, and heavy precipitation by 2100	Menendez and Carril (2010)	7 CMIP3 models, A1B	Warm nights: +10% to +30%; CDDs: +1 to +5 days; heavy precipitation: +3% to +9%
	Precipitation during summer and spring, and in fall and winter by 2100	Seth et al. (2010)	9 CMIP3 models, A2	Precipitation: +0.4 to +0.6 mm day^{-1}, –0.02 to –0.04 mm day^{-1}
	Warm nights, CDDs, and heavy precipitation by 2100	Marengo et al. (2009a, 2010)	PRECIS forced with HadAM3, A2	Increase of +6% to +12%, +5 to +20 days, +75 to +105 days
	Air temperature and rainfall by 2100	Giorgi and Diffenbaugh (2008)	23 CMIP3 models, A1B	Increase of +2°C to +4°C, increase of +20% to +30%
	CDDs and heavy precipitation by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Increase of +5% to +10% and of +2% to +8%
	Precipitation in north central Argentina, decrease in southern Brazil, increase of air temperature by 2100	Nuñez et al. (2009)	MM5 forced with HadAM3, A2	Increase of +0.5 to +1 mm day^{-1}, reduction of –0.5 mm day^{-1}, increase of +3°C to +4.5°C
	Drought frequency, intensity, and duration in SA south of 20°S for 2011–2040 relative to 1979–2008	Penalba and Rivera (2013)	15 CMIP5 models, RCP4.5 and 8.5	Frequency increase of 10–20%, increase in severity of 5–15%, and reduction in duration of 10–30%
	Precipitation, heavy precipitation, reduction of CDDs in the eastern part of the region, increase in the western part of the region by 2099	Sörensson et al. (2010)	RCA forced with ECHAM5, A1B	Increase of +2 mm day^{-1}, of +5 to +15 mm, reduction of –10 days and increase of +5 days
	Precipitation in southeastern SA by 2100	Sörensson et al. (2010)	9 CMIP3 models, A1B	Increase of +0.3 to +0.5 mm day^{-1}
Andes	Precipitation and temperature, increase by 2100 in the Altiplano	Minvielle and Garreaud (2011)	11 CMP3 models, A2	Precipitation: –10% to –30%; temperature: >3°C
	Precipitation at 5°N–5°S and 30°S–45°S, at 5°S–25°S; temperature by 2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Increase of +10% to +30%, decrease of –20% to –30%, increase of +3.5°C to +4.5°C
	Warm nights, heavy precipitation, and CDDs south of 15°S by 2100	Marengo et al. (2009a)	PRECIS forced with HadAM3, A2	Increase of +3% to +18%, reduction of –10 to –20 days, and reduction of –75 to –105 days
	Air temperature, rainfall between 0° and 10°S, and reduction between 10°S and 40°S	Giorgi and Diffenbaugh (2008)	23 CMIP3 models, A1B	Increase of +3°C to +4°C, increase of 10%, and reduction of –10%
	CDDs and increase of heavy precipitation by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Reduction of –5 days, increase of +2 to +4% south of 20°S
	Precipitation, heavy precipitation, and CDDs by 2070–2099	Sörensson et al. (2010)	RCA forced with ECHAM5, A1B	Increases of +1 to +3 mm day^{-1}, +5 mm and of +5 to +10 days
	Summer precipitation and surface air temperature in the Altiplano region by 2099	Minvielle and Garreaud (2011)	9 CMIP3 models, A2	Reduction in precipitation between –10% and –30%, and temperature increase of +3°C
	Temperature and rainfall in lowland Bolivia in 2070–2099	Seiler et al. (2013)	5 CMIP3 models (A1B) and 5 CMIP5 models (RCP4.5, 8.5)	Increase of 2.5°C to 5°C, reduction of 9% annual precipitation
	Precipitation in the dry season, temperature, and evapotranspiration 2079–2098	Guimberteau et al. (2013)	CMIP3 models, A1B	–1.1 mm; +2°C; +7%

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while Wang et al. (2011) suggests the importance of deforestation and vegetation dynamics on decadal variability of rainfall in the region. Costa and Pires (2010) have suggested a possible decrease in precipitation due to soybean expansion in Amazonia, mainly as a consequence of its very high albedo. In the South American Monsoon System (SAMS) region, positive trends in rainfall extremes have been identified in the last 30 years, with a pattern of increasing frequency and intensity of heavy rainfall events, and earlier onsets and late demise of the rainy season (see Table 27-1).

27.2.1.2. Climate Projections

Since the AR4, substantial additional regional analysis has been carried out using the Coupled Model Intercomparison Project Phase 3 (CMIP3) model ensemble. In addition, projections from CMIP5 models and new experiences using regional models (downscaling) have allowed for a better description of future changes in climate and extremes in CA and SA. Using CMIP3 and CMIP5 models, Giorgi (2006), Diffenbaugh et al. (2008), Xu et al. (2009), Diffenbaugh and Giorgi (2012), and Jones and Carvalho (2013) have identified areas of CA/western North America and the Amazon as persistent regional climate change hotspots throughout the 21st century of the Representative Concentration Pathway (RCP)8.5 and RCP4.5. Table 27-2 summarizes projected climatic changes derived from global and regional models for the region, indicating the projected change, models, emission scenarios, time spans, and references.

In CA and Northern Venezuela, projections from CMIP3 models and from downscaling experiments suggest precipitation reductions and warming together with an increase in evaporation, and reductions in

Table 27-2 (continued)

Region	Variable	Reference	Models and scenarios	Projected changes
Amazon region	Rainfall in central and eastern Amazonia and in western Amazonia; air temperature in all regions by 2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Precipitation: –20% to –30%, +20% to +30%; temperature: +5°C to +7°C
	Intensity of the South Atlantic Convergence Zone and in rainfall in the South American monsoon region, 2081–2100	Bombardi and Carvalho (2009)	10 CMIP3 models, A1B	Precipitation: –100 to –200 mm over 20 years
	Precipitation in western Amazonia during summer and in winter in Amazonia by 2100	Mendes and Marengo (2010)	5 CMIP3 models, A2 and ANN	+1.6% in summer and –1.5% in winter
	Number of South American Low Level Jet (SALLJ) events east of the Andes, and the moisture transport from Amazonia to the La Plata basin by 2090	Soares and Marengo (2009)	PRECIS forced with HadAM3, A2	+50% SALLJ events during summer, increase in moisture transport by 50%
	Precipitation in the South American monsoon during summer and spring, and during fall and winter by 2100	Seth et al. (2010)	9 CMIP3 models, A2	Increase of +0.15 to +0.4 mm/day, reductions of –0.10 to –0.26 mm/day
	Warm nights, CDDs in eastern Amazonia; heavy precipitation in western Amazonia and in eastern Amazonia by 2100	Marengo et al. (2009a)	PRECIS forced with HadAM3, A2	Increase of +12% to +15%, of 25–30 days in eastern Amazonia, increase in western Amazonia of 75–105 days, and reduction of –15 to –75 days in eastern Amazonia
	Increase in air temperature; rainfall increase in western Amazonia and decrease in eastern Amazonia by 2100	Giorgi and Diffenbaugh (2008)	CMIP3 models, A1B	Increase of +4°C to +6°C, increase of +10%, and decrease between –10% and –30%
	Reduction of CDDs and increase in heavy precipitation by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Reduction of –5 to –10 days, increase of +2% to +8%
	Onset and late demise of the rainy season in South American Monsoon System (SAMS) by 2040–2050 relative to 1951–1980	Jones and Carvalho (2013)	10 CMIP5 models, RCP8.5	Onset 14 days earlier than present, demise 17 days later than present
	Precipitation in SAMS during the monsoon wet season in 2071–2100 relative to 1951–1980	Jones and Carvalho (2013)	10 CMIP5 models, RCP8.5	Increase of 300 mm during the wet season
	Precipitation in western Amazonia, heavy precipitation in northern Amazonia and in southern Amazonia, CDDs in western Amazonia and increase by 2099	Sörensson et al. (2010)	RCA forced with ECHAM5, A1B	Increase of +1 to +3 mm day^{-1}, reduction of –1 to –3 mm, increase of +5 to +10 mm, decrease of –5 to –10 days, increase of +20 to +30 days
Northeastern Brazil	Rainfall and temperature in the entire region by 2100	Marengo et al. (2011a)	Eta forced with HadCM3, A1B	Precipitation: –20% to +20%; temperature: +3°C to +4°C
	Warm nights, CDDs, heavy precipitation by 2100	Marengo et al. (2009a)	PRECIS forced with HadAM3, A2	Increase of +18% to +24%, of +25 to +30 days, and –15 to –75 days
	Air temperature and precipitation by 2100	Giorgi and Diffenbaugh (2008)	23 CMIP3 models, A1B	Increase of +2°C to +4°C, reduction of –10% to –30%
	CDDs and heavy precipitation by 2099	Kamiguchi et al. (2006)	20 km MRI-AGCM3.1S model, A1B	Reduction of –5% to –10%, increase of +2% to +6%
	Precipitation, heavy precipitation, and CDDs by 2099	Sörensson et al. (2010)	RCA forced with ECHAM5, A1B	Increase of +1 to +2 mm day^{-1}, increase of +5 to +10 mm, and increase of +10 to +30 days

soil moisture for most of the land during all seasons by the end of the 21st century (see references in Table 27-2). However, the spread of projections is high for future precipitation.

Analyses from global and regional models in tropical and subtropical SA show common patterns of projected climate in some sectors of the continent. Projections from CMIP3 regional and high-resolution global models show by the end of the 21st century, for the A2 emission scenario, a consistent pattern of increase of precipitation in SESA, northwest of Peru and Ecuador, and western Amazonia, while decreases are projected for northern SA, eastern Amazonia, central eastern Brazil, NEB, the Altiplano, and southern Chile (Table 27-2). For some regions, projections show mixed results in rainfall projections for Amazonia and the SAMS region, suggesting high uncertainties on the projections (Table 27-2).

As for extremes, CMIP3 models and downscaling experiments show increases in dry spells are projected for eastern Amazonia and NEB, while rainfall extremes are projected to increase in SESA, in western Amazonia, northwest Peru, and Ecuador, while over southern Amazonia, NEB, and eastern Amazonia, the maximum number of consecutive dry days tends to augment, suggesting a longer dry season. Increases in warm nights throughout SA are also projected by the end of the 21st century (see references in Table 27-2). Shiogama et al. (2011) suggest that, although the CMIP3 ensemble mean assessment suggested wetting across most of SA, the observational constraints indicate a higher probability of drying in the eastern Amazon basin.

The CMIP5 models project an even larger expansion of the monsoon regions in NAMS in future scenarios (Jones and Carvalho, 2013; Kitoh et al., 2013). A comparison from eight models from CMIP3 and CMIP5 identifies some improvements in the new generation models. For example, CMIP5 inter-model variability of temperature in summer was lower over northeastern Argentina, Paraguay, and northern Brazil, in the last decades of the 21st century, as compared to CMIP3. Although

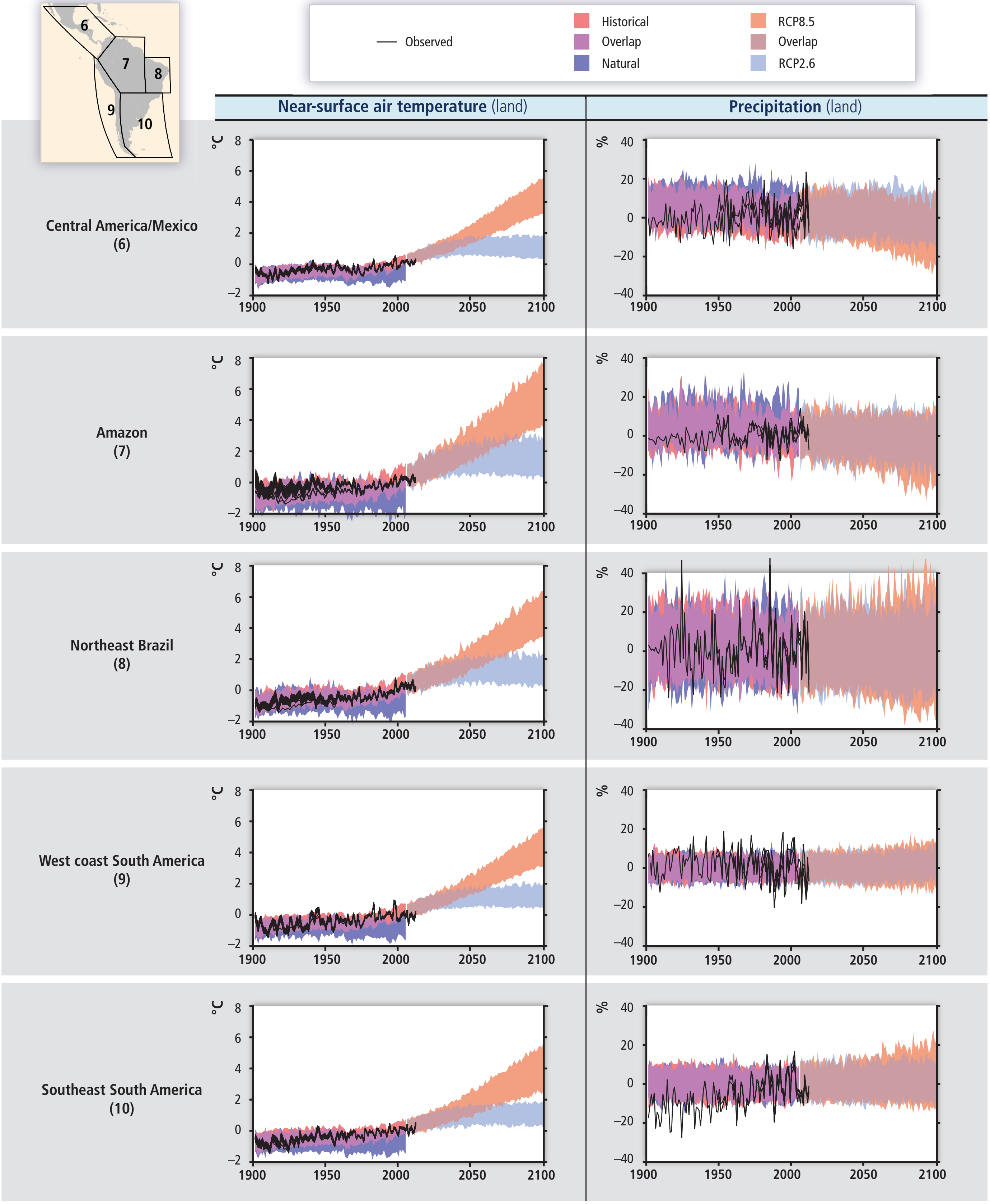

Figure 27-1 | Observed and simulated variations in past and projected future annual average temperature over the Central and South American regions defined in IPCC (2012a). Black lines show various estimates from observational measurements. Shading denotes the 5th to 95th percentile range of climate model simulations driven with "historical" changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), the Representative Concentration Pathway (RCP)2.6 emissions scenario (63), and RCP8.5 (63). Data are anomalies from the 1986–2006 average of the individual observational data (for the observational time series) or of the corresponding historical all-forcing simulations. Further details are given in Table SM21-5.

no major differences were observed in both precipitation data sets, CMIP5 inter-model variability was lower over northern and eastern Brazil in the summer by 2100 (Blázquez and Nuñez, 2013; Jones and Carvalho, 2013).

The projections from the CMIP5 models at regional level for CA and SA (using the same regions from SREX) are shown in Figure 27-1, and update some of these previous projections based on SRES A2 and B2 emission scenarios from CMIP3. Figure 27-1 shows that in relation to the baseline period 1986–2005, for CA and northern SA–Amazonia, temperatures are projected to increase by approximately 0.6°C and 2°C for the RCP2.6 scenario, and by 3.6°C and 5.2°C for the RCP8.5 scenario. For the rest of SA, increases by about 0.6°C to 2°C are projected for the RCP4.5 and by about 2.2°C to 7°C for the RCP8.5 scenario. The observed records show increases of temperature from 1900 to 1986 by about 1°C. For precipitation, while for CA and northern SA–Amazonia precipitation is projected to vary between +10 and –25% (with a large spread among models). For NEB, there is a spread among models between +30 and –30%, making it hard to identify any projected rainfall change. This spread is much lower in the western coast of SA and SESA, where the spread is between +20 and –10% (Chapter 21; Box 21-3).

CMIP5-derived RCP8.5 projections for the late 21st century, as depicted in Figure 27-2, follow: CA – mean annual warming of 2.5°C and rainfall reduction of 10%, and reduction in summertime precipitation; SA – mean warming of 4°C, with rainfall reduction up to 15% in tropical SA east of the Andes, and an increase of about 15 to 20% in SESA and in other regions of the continent. Changes shown for the mid-21st century are small. Both Figures 27-1 and 27-2 illustrate that there is some degree of uncertainty on climate change projections for regions, particularly for rainfall in CA and tropical SA.

27.2.2. Non-Climatic Stressors

27.2.2.1. Trends and Projections in Land Use and Land Use Change

Land use change is a key driver of environmental degradation for the region that exacerbates the negative impacts from climate change (Sampaio et al., 2007; Lopez-Rodriguez and Blanco-Libreros, 2008). The high levels of deforestation observed in most of the countries in the region have been widely discussed in the literature as a deliberate development strategy based on the expansion of agriculture to satisfy the growing world demand for food, energy, and minerals (Benhin, 2006; Grau and Aide, 2008; Müller et al., 2008). Land is facing increasing pressure from competing uses, among them cattle ranching, food, and bioenergy production. The enhanced competition for land increases the

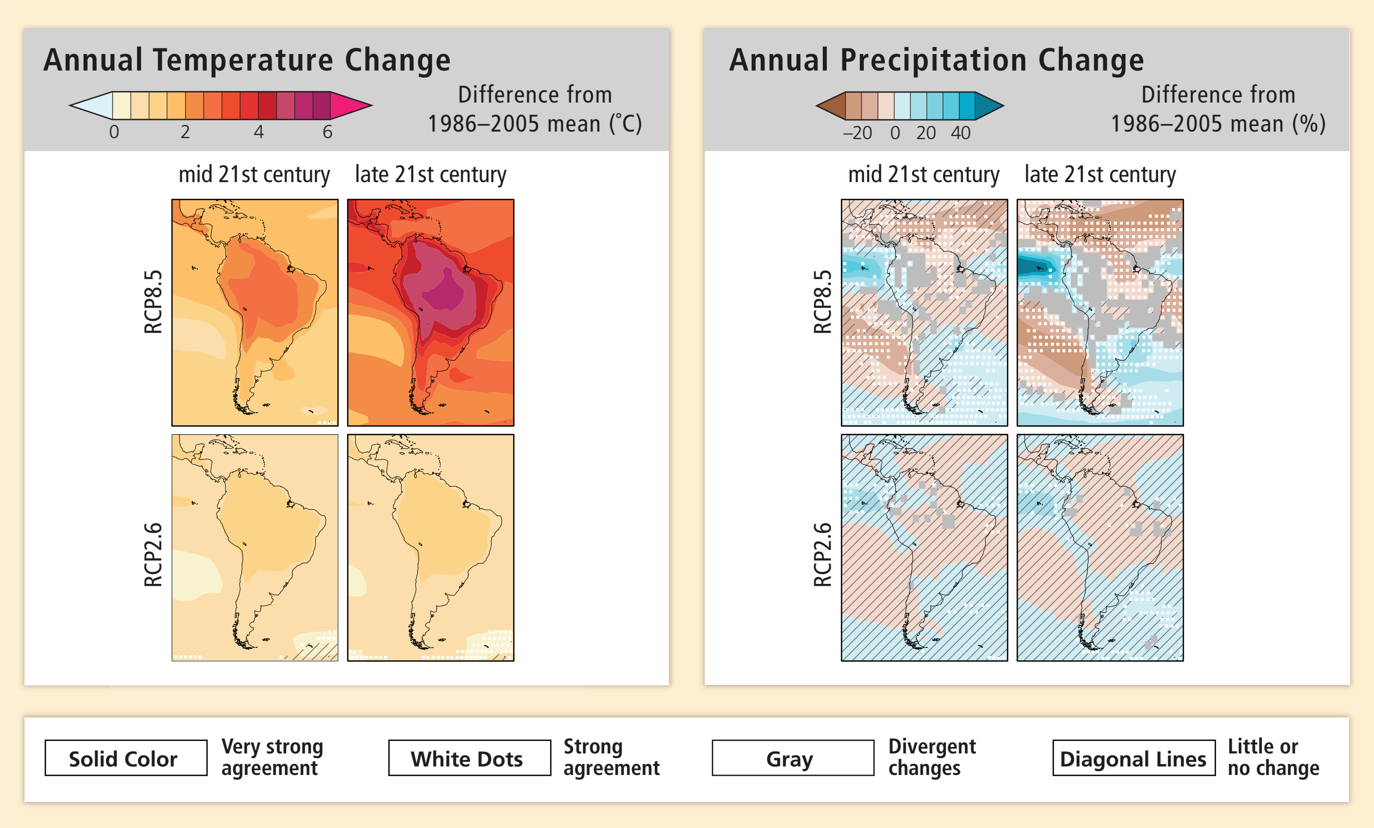

Figure 27-2 | Projected changes in annual average temperature and precipitation. CMIP5 multi-model mean projections of annual average temperature changes (left panel) and average percent changes in annual mean precipitation (right panel) for 2046–2065 and 2081–2100 under RCP2.6 and 8.5, relative to 1986–2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability (natural internal variability in 20-yr means) 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, where <66% of models show change greater than the baseline variability, although 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 21-2 and CC-RC] risk of land use changes, which may lead to negative environmental and socioeconomic impacts. Agricultural expansion has relied in many cases on government subsidies, which have often resulted in lower land productivity and more land speculation (Bulte et al., 2007; Roebeling and Hendrix, 2010). Some of the most affected areas due to the expansion of the agricultural frontier are fragile ecosystems such as the edges of the Amazon forest in Brazil, Colombia, Ecuador, and Peru, and tropical Andes including the Paramo, where activities such as deforestation, agriculture, cattle ranching, and gold mining are causing severe environmental degradation (ECLAC, 2010d), and the reduction of environmental services provided by these ecosystems.

Deforestation rates for the region remain high in spite of a reducing trend in the last decade (Ramankutty et al., 2007; Fearnside, 2008). Brazil is by far the country with the highest area of forest loss in the world according to the latest Food and Agriculture Organization (FAO) statistics (2010): 21,940 km² yr⁻¹, equivalent to 39% of world deforestation for the period 2005–2010. Bolivia, Venezuela, and Argentina follow in deforested area (Figure 27-3), with 5.5, 5.2, and 4.3% of the total world deforestation, respectively. The countries of CA and SA lost a total of 38,300 km² of forest per year in that period (69% of the total world deforestation; FAO, 2010). These numbers are limited by the fact that many countries do not have comparable information through time, particularly for recent years. Aide et al. (2013) completed a wall-to-wall analysis for the region for the period 2001–2010, analyzing not only deforestation but also reforestation, and reported very different results than FAO (2010) for some countries where reforestation seems to be higher than deforestation, particularly in Honduras, El Salvador, Panama, Colombia, and Venezuela. For Colombia and Venezuela, these results are contradictory with country analyses that align better with the FAO data (Rodríguez, J.P. et al., 2010; Armenteras et al., 2013).

Deforestation in the Amazon forest has received much international attention in the last decades, both because of its high rates and its rich biodiversity. Brazilian Legal Amazon is now one of the best-monitored ecosystems in terms of deforestation since 1988 (INPE, 2011). Deforestation for this region peaked in 2004 and has steadily declined since then to a lowest value of 4656 km² yr⁻¹ for the year 2012 (see

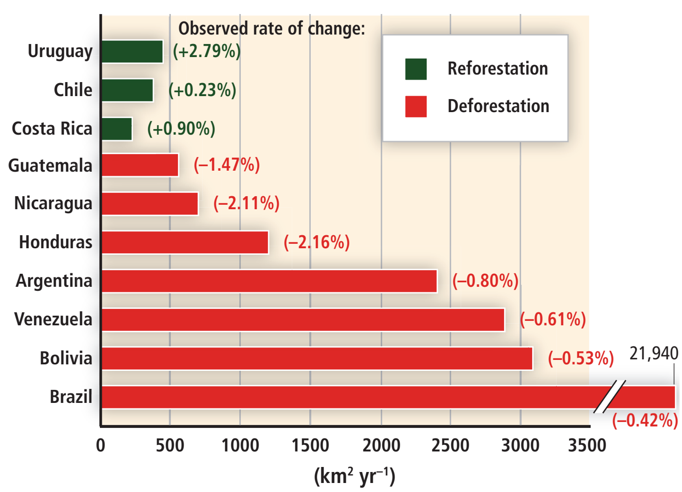

Figure 27-3 | Forest cover change per year for selected countries in Central and South America (2005–2010). Notice three countries listed with a positive change in forest cover (based on data from FAO, 2010).

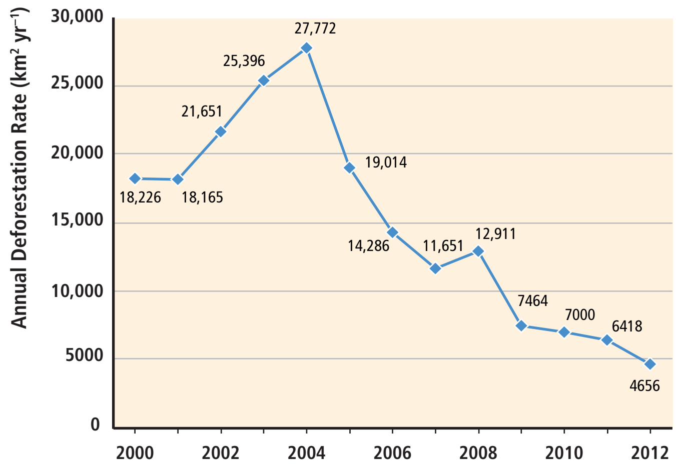

Figure 27-4 | Deforestation rates in Brazilian Amazonia (km² yr⁻¹) based on measurements by the PRODES project (INPE, 2011).

Figure 27-4). Such reduction results from a series of integrated policies to control illegal deforestation, particularly enforcing protected areas, which now shelter 54% of the remaining forests of the Brazilian Amazon (Soares-Filho et al., 2010). Deforestation in Brazil is now highest in the Cerrado (drier ecosystem south of Amazon), with an average value of 14,179 km² yr⁻¹ for the period 2002–2008 (FAO, 2009).

The area of forest loss in CA is considerably less than in SA, owing to smaller country sizes (Carr et al., 2009), but when relative deforestation rates are considered, Honduras and Nicaragua show the highest values for CA and SA (FAO, 2010). At the same time, CA includes some countries where forest cover shows a small recovery trend in the last years: Costa Rica, El Salvador, Panama, and possibly Honduras, where data are conflicting in the literature (FAO, 2010; Aide et al., 2013). This forest transition is the result of (1) economies less dependent on agriculture, and more on industry and services (Wright and Samaniego, 2008); (2) processes of international migration with the associated remittances (Hecht and Saatchi, 2007); and (3) a stronger emphasis on the recognition of environmental services of forest ecosystems (Kaimowitz, 2008). The same positive trend is observed in some SA countries (Figure 27-3). However, a substantial amount of forest is gained through (single-crop) plantations, most noticeably in Chile (Aguayo et al., 2009), which has a much lower ecological value than the depleted natural forests (Echeverría et al., 2006; Izquierdo et al., 2008).

Land degradation is also an important process compromising extensive areas of CA and SA very rapidly. According to data from the Global Land Degradation Assessment and Improvement (GLADA) project of the Global Environmental Facility (GEF), additional degraded areas reached 16.4% of the entire territory of Paraguay, 15.3% of Peru, and 14.2% of Ecuador for the period 1982–2002. In CA, Guatemala shows the highest proportion of degraded land, currently at 58.9% of the country's territory, followed by Honduras (38.4%) and Costa Rica (29.5%); only El Salvador shows a reversal of the land degradation process, probably due to eased land exploitation following intensive international migratory processes (ECLAC, 2010d).

Deforestation and land degradation are attributed mainly to increased extensive and intensive agriculture. Two activities have traditionally dominated the agricultural expansion: soy production (only in SA) and beef. But, more recently, biomass for biofuel production has become as important (Nepstad and Stickler, 2008) with some regions also affected by oil and mining extractions. Deforestation by small farmers, coming mainly from families who migrate in search for land, is relatively low: extensive cattle production is the predominant land use in deforested areas of tropical and subtropical Latin America (Wassenaar et al., 2007). Cattle is the only land use variable correlated with deforestation in Colombia (Armenteras et al., 2013), and in the Brazilian Amazon the peak of deforestation in 2004 (Figure 27-4) was primarily the result of increased cattle ranching (Nepstad et al., 2006). Mechanized farming, agro-industrial production, and cattle ranching are the major land use change drivers in eastern Bolivia but subsistence agriculture by indigenous colonists is also important (Killeen et al., 2008).

In recent years, soybean croplands have expanded continuously in SA, becoming increasingly more important in the agricultural production of the region. Soybean-planted area in Amazonian states (mainly Mato Grosso) in Brazil expanded 12.1% per year during the 1990s, and 16.8% per year from 2000 to 2005 (Costa et al., 2007). This landscape-scale conversion from forest to soy and other large-scale agriculture can alter substantially the water balance for large areas of the region, resulting in important feedbacks to the local climate (Hayhoe et al., 2011; Loarie et al., 2011; see Section 27.3.4.1).

Soybean and beef production have also impacted other ecosystems next to the Amazon, such as the Cerrado (Brazil) and the Chaco dry forests (Bolivia, Paraguay, Argentina, and Brazil). Gasparri et al. (2008) estimated carbon emissions from deforestation in northern Argentina, and concluded that deforestation in the Chaco forest has accelerated in the past decade from agricultural expansion and is now the most important source of carbon emissions for that region. In northwest Argentina (Tucumán and Salta provinces), 14,000 km^2 of dry forest were cleared from 1972 to 2007 as a result of technological improvements and increasing rainfall (Gasparri and Grau, 2009). Deforestation continued during the 1980s and 1990s, resulting in cropland area covering up to 63% of the region by 2005 (Viglizzo et al., 2011). In central Argentina (northern Córdoba province), cultivated lands have increased from 3 to 30% (between 1969 and 1999); and the forest cover has decreased from 52.5 to 8.2%. This change has also been attributed to the synergistic effect of climatic, socioeconomic, and technological factors (Zak et al., 2008). Losses in the Atlantic forest are estimated in 29% of the original area in 1960, and in 28% of the Yunga forest area, mainly due to cattle ranching migration from the Pampas and Espinal (Viglizzo et al., 2011).

Palm oil is a significant biofuel crop also linked to recent deforestation in tropical CA and SA. Its magnitude is still small compared with deforestation related to soybean and cattle ranching, but is considerable for specific countries and expected to increase due to increasing demands for biofuels (Fitzherbert et al., 2008). The main producers of palm oil in the region are Colombia and Ecuador, followed by Costa Rica, Honduras, Guatemala, and Brazil; Brazil has the largest potential for expansion, as nearly half of the Amazonia is suitable for oil palm cultivation (Butler and Laurance, 2009). Palm oil production is also growing in the Amazonian region of Peru, where 72% of new plantations have expanded into forested areas, representing 1.3% of the total deforestation for that country for the years 2000–2010 (Gutiérrez-Vélez et al., 2011).

However, forests are not the only important ecosystems threatened in the region. An assessment of threatened ecosystems in SA by Jarvis et al. (2010) concluded that grasslands, savannahs, and shrublands are more threatened than forests, mainly from excessively frequent fires (>1 yr^{-1}) and grazing pressure. An estimation of burned land in LA by Chuvieco et al. (2008) also concluded that herbaceous areas presented the highest occurrence of fires. In the Río de la Plata region (central-east Argentina, southern Brazil, and Uruguay), grasslands decreased from 67.4 to 61.4% between 1985 and 2004. This reduction was associated with an increase in annual crops, mainly soybean, sunflower, wheat, and maize (Baldi and Paruelo, 2008).

Even with technological changes that might result in agricultural intensification, the expansion of pastures and croplands is expected to continue in the coming years (Wassenaar et al., 2007; Kaimowitz and Angelsen, 2008), particularly from an increasing global demand for food and biofuels (Gregg and Smith, 2010) with the consequent increase in commodity prices. This agricultural expansion will be mainly in LA and sub-Saharan Africa as these regions hold two-thirds of the global land with potential to expand cultivation (Nepstad and Stickler, 2008). It is important to consider the policy and legal needs to keep this process of large-scale change under control as much as possible; Takasaki (2007) showed that policies to eliminate land price distortions and promote technological transfers to poor colonists could reduce deforestation. It is also important to consider the role of indigenous groups; there is a growing acknowledgment that recognizing the land ownership and authority of indigenous groups can help central governments to better manage many of the natural areas remaining in the region (Oltremari and Jackson, 2006; Larson, 2010). The impact of indigenous groups on land use change can vary: de Oliveira et al. (2007) found that only 9% of the deforestation in the Peruvian Amazon between 1999 and 2005 happened in indigenous territories, but Killeen et al. (2008) found that Andean indigenous colonists in Bolivia were responsible for the largest land cover changes in the period 2001–2004. Indigenous groups are important stakeholders in many territories in the region and their well-being should be considered when designing responses to pressures on the land by a globalized economy (Gray et al., 2008; Killeen et al., 2008).

27.2.2.2. Trends and Projections in Socioeconomic Conditions

Development in the region has traditionally displayed four characteristics: low growth rates, high volatility, structural heterogeneity, and very unequal income distribution (ECLAC, 2008; Bárcena, 2010). This combination of factors has generated high and persistent poverty levels (45% for CA and 30% for SA for year 2010), with the rate of poverty being generally higher in rural than urban areas (ECLAC, 2009b). SA has based its economic growth in natural resource exploitation (mining, energy, agricultural), which involves direct and intensive use of land and water, and in energy-intensive and, in many cases, highly polluting natural resource-based manufactures. In turn, CA has exploited its proximity to the North American market and its relatively low labor costs (ECLAC, 2010e). The region shows a marked structural heterogeneity, where modern production structures coexist with large segments of the population with low productivity and income levels (ECLAC, 2010g). The gross domestic product (GDP) per capita in SA is twice that of CA; in addition, in the latter, poverty is 50% higher (see Figure 27-5).

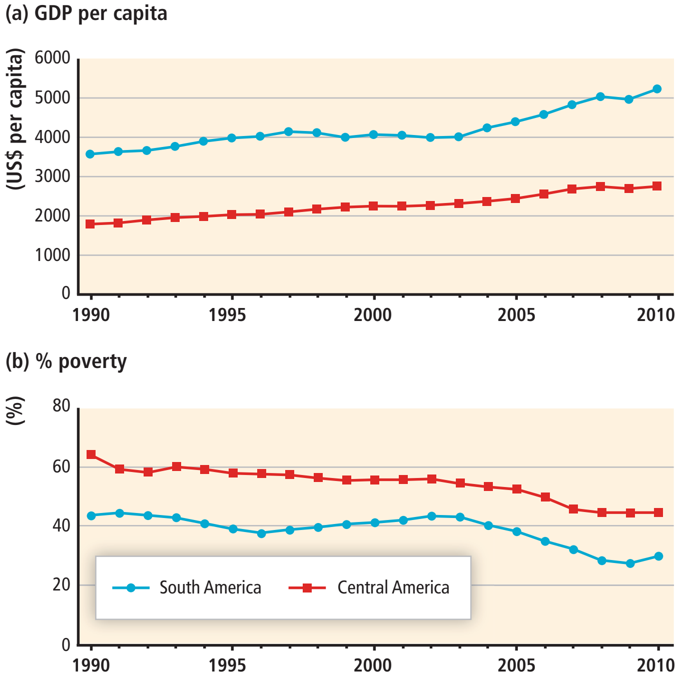

Figure 27-5 | Evolution of GDP per capita and poverty (income below US$2 per day) from 1990–2010: Central and South America (US$ per inhabitant at 2005 prices and percentages) (ECLAC, 2011c; 2012a).

The 2008 financial crisis reached CA and SA through exports and credits, remittances, and worsening expectations by consumers and producers (Bárcena, 2010; Kacef and López-Monti, 2010). This resulted in the sudden stop of six consecutive years of robust growth and improving social indicators (ECLAC, 2010e), which contributed to higher poverty in 2009 after 6 years where poverty had declined by 11%. Poverty rates fell from 44 to 33% of the total population from 2003 to 2008 (Figure 27-5), leaving 150 million people in this situation while extreme poverty diminished from 19.4 to 12.9% (which represents slightly more than 70 million people) (ECLAC, 2009b).

In the second half of 2009, industrial production and exports began to recover and yielded a stronger economic performance (GDP growth of 6.4% in SA and 3.9% in CA in 2010; ECLAC, 2012b). SA benefited the most because of the larger size of their domestic markets and the greater diversification of export markets. Conversely, slower growth was observed in CA, with more open economies and a less diversified portfolio of trading partners and a greater emphasis on manufacturing trade (ECLAC, 2010g).

The region is expected to continue to grow in the short term, albeit at a pace that is closer to potential GDP growth, helped by internal demand as the middle class becomes stronger and as credit becomes more available. In SA, this could be boosted by external demand from the Asian economies as they continue to grow at a rapid pace. The macroeconomic challenge is to act counter cyclically, creating conditions for productive development that is not based solely on commodity exports (ECLAC, 2010f).

In spite of its economic growth, CA and SA still display high and persistent inequality: most countries have Gini coefficients between 0.5 and 0.6, whereas the equivalent figures in a group of 24 developed countries vary between under 0.25 and around 0.4. The average per capita income of the richest 10% of households is approximately 17 times that of the poorest 40% of households (ECLAC, 2010g). Nevertheless, during the first decade of the century, prior to the financial crisis, the region has shown a slight but clear trend toward a more equitable distribution of income and a stronger middle class population, resulting in a higher demand for goods (ECLAC, 2010g,h, 2011b). Latin American countries also reported gains in terms of human development, although these gains have slowed down slightly over recent years. In comparative terms, as measured by the Human Development Index (HDI), the performance of countries varied greatly in 2007 (from Chile with 0.878 and Argentina with 0.866 to Guatemala with 0.704 and Nicaragua with 0.699), although those with lower levels of HDI showed notably higher improvements than countries with the highest HDI (UNDP, 2010).

Associated with inequality are disparities in access to water, sanitation, and adequate housing for the most vulnerable groups—for example, indigenous peoples, Afro-descendants, children, and women living in poverty—and in their exposure to the effects of climate change. The strong heterogeneity of subnational territorial entities in the region takes the form of high spatial concentration and persistent disparities in the territorial distribution of wealth (ECLAC, 2010g,h, 2011b).

The region faces significant challenges in terms of environmental sustainability and adaptability to a changing climate (ECLAC, 2010h), resulting from the specific characteristics of its population and economy already discussed and aggravated with a significant deficit in infrastructure development. CA and SA countries have made progress in incorporating environmental protection into decision-making processes, particularly in terms of environmental institutions and legislation, but there are still difficulties to effectively incorporate environmental issues into relevant public policies (ECLAC, 2010h). Although climate change imposes new challenges, it also provides an opportunity to shift development and economic growth patterns toward a more environmentally friendly course.

27.3. Impacts, Vulnerabilities, and Adaptation Practices

27.3.1. Freshwater Resources

CA and SA are regions with high average but unevenly distributed water resources availability (Magrin et al., 2007a). The main user of water is agriculture, followed by the region's 580 million inhabitants (including the Caribbean), of which 86% had access to water supply by 2006 (ECLAC, 2010b). According to the International Energy Agency (IEA), the region meets 60% of its electricity demand through hydropower generation, which contrasts with the 20% average contribution of other regions (see Table 27-6 and case study in Section 27.6.1).

27.3.1.1. Observed and Projected Impacts and Vulnerabilities

In CA and SA there is much evidence of changing hydrologic related conditions. The most robust trend for major rivers is found in the sub-basins of the La Plata River basin (*high confidence,* based on *robust* *evidence*, *high agreement*). This basin, second only to the Amazon in size, shows a positive trend in streamflow in the second half of the 20th century at different sites (Pasquini and Depetris, 2007; Krepper et al., 2008; Saurral et al., 2008; Amsler and Drago, 2009; Conway and Mahé, 2009; Dai et al., 2009; Krepper and Zucarelli, 2010; Dai, 2011; Doyle and Barros, 2011). An increase in precipitation and a reduction in evapotranspiration from land use changes have been associated with the trend in streamflows (Saurral et al., 2008; Doyle and Barros, 2011), with the former being more important in the southern sub-basins and the latter in the northern ones (Doyle and Barros, 2011; see Section 27.2.1). Increasing trends in streamflows have also been found in the Patos Lagoon in southern Brazil (Marques, 2012) and Laguna Mar Chiquita (a closed lake), and in the Santa Fe Province, both in Argentina, with ecological and erosive consequences (Pasquini et al., 2006; Rodrigues Capítulo et al., 2010; Troin et al., 2010; Venencio and García, 2011; Bucher and Curto, 2012).

Table 27-3 | Observed trends related to Andean cryosphere. (LIA = Little Ice Age; w.e. = water equivalent.)

(a) Andean tropical glacier trends.

Country	Documented massifs	Latitude	Significant changes recorded		References
			Variable code number[a]	Description of trend [period of observed trend]	
Venezuela	Cordillera de Mérida	10°N	1	+300 to +500 m [between LIA maximum and today]	Morris et al. (2006); Polissar et al. (2006)
			5	Accelerated melting [since 1972]. Risk of disappearing completely, as equilibrium line altitude is close to the highest peak (Pico Bolívar, 4979 m)	
Colombia	Parque Los Nevados	4°50’N	3	LIA maximum between 1600 and 1850	Ceballos et al. (2006); Ruiz et al. (2008); Poveda and Pineda (2009); IDEAM (2012); Rabatel et al. (2013)
	Sierra Nevada del Cocuy	6°30’N	3	Many small/low elevation glaciers (<5000 meters above sea level) have disappeared.	
	Sierra Nevada de Santa Marta	10°40’N	3	–60 to –84% [1850–2000]; –50% [last 50 years]; –10 to –50% [past 15 years]; retreat 3.0 km^2 $year^{-1}$ [since 2000]	
Ecuador	Antisana	0°28’S	1	+300 m [between the middle of the 18th century (LIA maximum) and the last decades of the 20th century]; about +200 m [20th century]	Francou et al. (2007); Vuille et al. (2008); Jomelli et al. (2009); Cáceres (2010); Rabatel et al. (2013)
	Chimborazo and Carihuayrazo	1°S	3	About –45% [1976–2006]. Glaciers below 5300 m in process of extinction	
Peru	Cordillera Blanca	9°S	1	About +100 m [between LIA maximum and beginning of the 20th century]; +150 m [20th century]	Raup et al. (2007); Jomelli et al. (2009); Mark et al. (2010); UGHR (2010); Bury et al. (2011); Baraer et al. (2012); Rabatel et al. (2013)
			3	–12 to –17% [18th century]; –17 to –20% [19th century]; –20 to –35% [1960s–2000s]	
			4	–8 m $decade^{-1}$ [since 1970] (Yanamarey glacier)	
			8	+1.6% (±1.1) (watersheds with >20% glacier area)	
			8	Seven out of nine watersheds decreasing dry-season discharge	
	Coropuna volcano	15°33’S	3	–26% [1962–2000]	Racoviteanu et al. (2007)
	Cordillera Vilcanota	13°55’S	3	10 times faster [in 1991–2005 compared to 1963–2005]	Thompson et al. (2006, 2011)
			3, 5	About –30% area and about –45% volume [since 1985]	Salzmann et al. (2013)
Bolivia	Cordillera Real and Cordillera Quimsa Cruz	16°S	1	+300 m [between LIA maximum and late 20th century]; +180 to +200 m [20th century]	Rabatel et al. (2006, 2008); Francou et al. (2007); Vuille et al. (2008); Soruco et al. (2009); Gilbert et al. (2010); Jomelli et al. (2011); Rabatel et al. (2013)
			3	–48% [1976–2006] in the Cordillera Real; Chacaltaya vanished [in 2010].	
			5	Zongo glacier has lost a mean of 0.4 m (w.e.) $year^{-1}$ [in the 1991–2011 period]; glaciers in the Cordillera Real lost 43% of their volume [1963–2006; maximum rate of loss in 1976–2006].	
			2	+1.1°C ± 0.2°C [over the 20th century] at about 6340 meters above sea level	
	Caquella rock glacier (South Bolivian Altiplano)	21°30’S	7	Evidence of recent degradation	Francou et al. (1999)

(b) Extratropical Andean cryosphere (glaciers, snowpack, runoff effects) trends.

Region	Documented massifs/sites	Latitude	Significant changes recorded		References
			Variable code number[a]	Value of trend [period of observed trend]	
Chile, Argentina, Bolivia, and Argentinean Patagonia		South of 15°S	6	No significant trend	Foster et al. (2009)
Desert Andes (17°S–31°S)	Huasco basin glaciers	29°S	5	–0.84 m (w.e.) $year^{-1}$ [2003/2004–2007/2008]	Nicholson et al. (2009); Gascoin et al. (2011); Rabatel et al. (2011)

Continued next page →

Table 27-3(b) (continued)

Region	Documented massifs/sites	Latitude	Significant changes recorded		References
			Variable code number[a]	Value of trend [period of observed trend]	
Central Andes (31°S–36°S)	Piloto/Las Cuevas	32°S	5	–10.50 m (w.e.) [last 24 years]	Leiva et al. (2007)
	Aconcagua basin glaciers	33°S	3	–20% [last 48 years]	Pellicciotti et al. (2007); Bown et al. (2008)
			3	–14% [1955–2006]	
			8	Significant decrease in Aconcagua basin streamflow	
	Central Andes glaciers	33°S–36°S	3	–3% [since 1955]	Le Quesne et al. (2009)
			4	–50 to –9 m year^{-1} [during 20th century]	
			5	–0.76 to –0.56 m (w.e.) year^{-1} [during 20th century]	
	Central Andes		1	+122 ± 8 m (winter) and +200 ± 6 m (summer) [1975–2001]	Carrasco et al. (2005)
	Snowpack	30°S–37°S	6	Positive, though nonsignificant, linear trend [1951–2005]	Masiokas et al. (2006); Vich et al. (2007); Vicuña et al. (2013)
			8	Mendoza River streamflow: possible link to rising temperatures and snowpack/glacier effects. Not conclusive; increase in high and low flows possibly associated with increase in temperature and effects on snowpack	
	Morenas Coloradas rock glacier	32°S–33°S	7	Significant change in active layer possibly associated with warming processes	Trombotto and Borzotta (2009)
	Cryosphere in the Andes of Santiago	33.5°S	5	Expansion of thermokarst depressions	Bodin et al. (2010)
	Basins	28°S–47°S	8	Non-significant increase in February runoff; possible increase of glacier melt [1950–2007]	Casassa et al. (2009)
		30°S–40°S	8	Significant negative timing trend (centroid timing date shifting toward earlier in the year) for 23 out of the 40 analyzed series	Cortés et al. (2011)
Patagonian Andes (36°S–55°S)	Basins	28°S–47°S	8	Not significant increase in February runoff trends that might suggest an increase of glacier melt in the Andes [1950–2007]	Casassa et al. (2009)
	Northwest Patagonia	38°S–45°S	4	Recession of six glaciers based on aerial photograph analysis	Masiokas et al. (2008)
	Proglacial lakes	40°S–50°S	8	Summertime negative trend on lakes indicating that melt water is decreasing	Pasquini et al. (2008)
	Casa Pangue glacier	41°S	5	–2.3 ± 0.6 m (w.e.) year^{-1} [1961–1998]	Bown and Rivera (2007)
			4	–3.6 ± 0.6 m year^{-1} [1981–1998]	
	Manso Glacier	41°S	8	Reduction in discharge associated with reduction in melt and precipitation	Pasquini et al. (2013)
	Patagonian Ice Field	47°S–51°S	5	–1.6 m (w.e.) year^{-1} or –27.9 ± 11 km^3 (w.e.) year^{-1} [2002–2006]	Chen et al. (2007)
	Northern Patagonian Ice Field	47°S	8	Glacial lake outburst flood possible response to retreat of Calafate glacier [20th century]	Harrison et al. (2006)
	Southern Patagonian Ice Field	48°S–51°S	4	Larger retreating rates observed on the west side coinciding with lower elevations of equilibrium line altitudes	Barcaza et al. (2009)
	Northern Patagonian, Southern Patagonian, and Cordillera Darwin ice fields	47°S–51°S, 54°S	4	5.7 to 12.2 km [1945–2005]	Lopez et al. (2010)
	Gran Campo Nevado	53°S	4	–2.8% of glacier length per decade [1942–2002]	Schneider et al. (2007)
			3	–2.4% per decade [1942–2002]	
	Cordón Martial glaciers	54°S	5	Slow retreat from late LIA. Acceleration started 60 years ago.	Sterlin and Iturraspe (2007)

[a]Variable coding: (1) Increase in equilibrium line altitude; (2) atmospheric warming revealed by englacial temperature measured at high elevation; (3) area reduction; (4) frontal retreat; (5) volume reduction; (6) snow cover; (7) rock glaciers; (8) runoff change.

There is no clear long-term trend for the Amazon River. Espinoza et al. (2009a, 2011) showed that the 1974–2004 apparent stability in mean discharge at the main stem of the Amazon in Obidos is explained by opposing regional features of Andean rivers (e.g., increasing trends during the high-water period in Peruvian and Colombian Amazons and decreasing trend during the low-water period in Peruvian and Bolivian Amazons (Lavado et al., 2012). In recent years extremely low levels were experienced during the droughts of 2005 and 2010, while record high levels were detected during the 2009 and 2012 floods (Section 27.2.1). Major Colombian rivers draining to the Caribbean Sea (Magdalena and Cauca) exhibit decreasing trends along their main channels (Carmona and Poveda, 2011), while significant trends are absent for all other major large rivers in NEB and northern SA (Dai et al., 2009). Dai (2011) showed a drying trend in CA rivers.

A rapid retreat and melting of the tropical Andes glaciers of Venezuela, Colombia, Ecuador, Peru, and Bolivia has been further reported following the IPCC AR4, through use of diverse techniques (*high confidence*, based

Table 27-4 | Synthesis of projected climate change impacts on hydrological variables in Central American and South American basins and major glaciers.

Region	Basins studied	Variable code number[a]	Projected change	Period	General circulation model (greenhouse gas scenario)	References
Río de La Plata Basin and Southeastern South America	Paraná River	1	+4.9% (not robust)	2081–2100	CMIP3 models (A1B)	Nohara et al. (2006)
			+10 to +20%	2100	Eta-HadCM3 (A1B)	Marengo et al. (2011a)
			+18.4% (significant)	2075–2100	CMIP3 models (A1B)	Nakaegawa et al. (2013a)
	Rio Grande	1	+20 to –20%	Different periods	7 CMIP3 models	Gosling et al. (2011); Nóbrega et al. (2011); Todd et al. (2011)
	Itaipu Power Plant (on the Paraná River)	1	Left bank: –5 to –15%; right bank: +30%	2010–2040	CCCMA–CGCM2 (A2)	Rivarola et al. (2011)
			0 to –30%	2070–2100		
	Concórdia River	1	–40%	2070–2100	HadRM3P (A2, B2)	Perazzoli et al. (2013)
	Carcarañá River	2	Increase	2010–2030	HadCM3 (A2)	Venencio and García (2011)
		3	Slight reduction			
Amazon Basin	Peruvian Amazon basins	1	Increase in some basins; reduction in others	Three time slices	BCM2, CSMK3 and MIHR (A1B, B1)	Lavado et al. (2011)
	Basins in region of Alto Beni, Bolivia	1	Increase and reduction	2070–2100	CMIP3 models (A1B)	Fry et al. (2012)
		3	Always reduction			
		5	Increase in water stress			
	Paute and Tomebamba Rivers	1	Increase in some scenarios; reduction in others	2070–2100	CMIP3 models (A1B)	Buytaert et al. (2011)
	Amazon River	1	+5.4% (not robust)	2081–2100	CMIP3 models (A1B)	Nohara et al. (2006)
			+6%	2000–2100	ECBilt–CLIO–VECODE (A2)	Aerts et al. (2006)
			+3.7% (significant)	2075–2100	CMIP3 models (A1B)	Nakaegawa et al. (2013a)
			At Óbidos Station: no change in high flow; reduction in low flow	2046–2065/ 2079–2098	8 AR4 GCMs (B1, A1B, and A2)	Guimberteau et al. (2013)
	Amazon and Orinoco Rivers	1	–20%	2050s	HadCM3 (A2)	Palmer et al.(2008)
	Basins in Brazil	1	Consistent decrease	2050s	HadCM3 and CMIP3 models (A1B)	Arnell and Gosling (2013)
Tropical Andes	Colombian glaciers	4	Disappearance by 2020s	Linear extrapolation		Poveda and Pineda (2009)
	Cordillera Blanca glacierized basins	1	Increase for next 20–50 years, reduction afterwards	2005–2020	Temperature output only (B2)	Chevallier et al. (2011)
		4	Area –38 to –60%. Increased seasonality	2050	Not specified (A1, A2, B1, B2)	Juen et al. (2007)
			Area –49 to –75%. Increased seasonality	2080		
			Increased seasonality	2030	16 CMIP3 models (A1B, B1)	Condom et al. (2012)
	Basins providing water to cities of Bogotá, Quito, Lima, and La Paz	5	Inner tropics: only small change; increase in precipitation and increase in evapotranspiration	2010–2039 and 2040–2069	19 CMIP3 models (A1B, A2)	Buytaert and De Bièvre (2012)
			Outer tropics: severe reductions; decrease in precipitation and increase in evapotranspiration			
Central Andes	Limarí River	1	–20 to –40%	2070–2100	HadCM3 (A2, B2)	Vicuña et al. (2011)
			–20%	2010–2040	15 CMIP3 models (A1B, B2, B1)	Vicuña et al. (2012)
			–30 to –40%; change in seasonality	2070–2100		
	Maipo River	1	–30%	Three 30-year periods	HadCM3 (A2, B2)	ECLAC (2009a); Melo et al. (2010); Meza et al. (2012)
		5	Unmet demand up to 50%	2070–2090		
	Mataquito River	1	Reduction in average and low flows Increase in high flows	Three 30-year periods	CMIP3 (A2, B1) and CMIP5 (RCP4.5 and 8.5) models	Demaria et al. (2013)
	Maule and Laja Rivers	1	–30%	Three 30-year periods	HadCM3 (A2, B2)	ECLAC (2009a); McPhee et al. (2010)
	Bío Bío River	1	–81 to +7%	2070–2100	8 GCMs (6 SRES)	Stehr et al. (2010)
	Limay River	1	–10 to –20%	2080s	HadCM2 (NS)	Seoane and López (2007)

Continued next page →

Table 27-4 (continued)

Region	Basins studied	Variable code number[a]	Projected change	Period	General circulation model (greenhouse gas scenario)	References
Northeastern Brazil	Basins in the Brazilian states of Ceará and Piauí	1	No significant change up to 2025. After 2025: strong reduction with ECHAM4; slight increase with HadCM2.	2000–2100	HadCM2, ECHAM4 (NS)	Krol et al. (2006); Krol and Bronstert (2007)
	Paracatu River	1	+31 to +131%	2000–2100	HadCM3 (A2)	De Mello et al. (2008)
			No significant change	2000–2100	HadCM3 (B2)	
	Jaguaribe River	2	Demand: +33 to +44%	2040	HadCM3 (A2, B2)	Gondim et al. (2008, 2012)
			Irrigation water needs: +8 to +9%	2025–2055	HadCM3 (B2)	
	Parnaíba River	1	–80%	2050s	HadCM3 (A2)	Palmer et al. (2008)
	Mimoso River	1	Dry scenario: –25 to –75%	2010–2039, 2040–2069, and 2070–2099	CSMK3 and HadCM3 (A2, B1)	Montenegro and Ragab (2010)
			Wet scenario: +40 to +140%			
		3	No change			
	Tapacurá River	1	B1: –4.89%, –14.28%, –20.58%	Three 30-year periods	CSMK3 and MPEH5 (A2, B1)	Montenegro and Ragab (2012)
			A2: +25.25%, +39.48%, +21.95%			
	Benguê Catchment	1	–15% reservoir yield	Sensitivity scenario in 2100 selected from Third and Fourth Assessment Report general circulation models with good skill. +15% potential evapostranspiration, –10% precipitation		Krol et al. (2011)
	Aquifers in northeastern Brazil	3	Reduction	2040–2070	HadCM3, ECHAM4 (A2,B2)	Hirata and Conicelli (2012)
Northern South America	Essequibo River	1	–50%	2050s	HadCM3 (A2)	Palmer et al. (2008)
	Magdalena River	1	Non-significant changes in near future. End of 21st century changes in seasonality.	2015–2035 and 2075–2099	CMIP3 multi-model ensemble (A1B)	Nakaegawa and Vergara (2010)
	Sinú River	1	–2 to –35%	2010–2039	CCSRNIES, CSIROMK2B, CGCM2, HadCM3 (A2)	Ospina-Noreña et al. (2009a,b)
Central America	Lempa River	1	–13%	2070–2100	CMIP3 models (B1)	Maurer et al. (2009)
			–24%	2070–2100	CMIP3 models (A2)	
	Río Grande de Matagalpa	1	–70%	2050s	HadCM3 (A2)	Palmer et al. (2008)
	Basins in Mesoamerica	1	Decrease across the region	2070–2100	CMIP3 (A2, A1B, B1)	Imbach et al. (2012)
			Consistent decrease	2050s	HadCM3 and CMIP3 models (A1B)	Arnell and Gosling (2013)
			Consistent reduction in northern CA	2050–2099	30 GCMs (A1B)	Hidalgo et al. (2013)
	Basins in Panama	1	Basins discharging into the Pacific: +35 to +40%	2075–2099	MRI-AGCM3.1 (A1B)	Fábrega et al. (2013)
			Basins in the Bocas del Toro region: –50%			

[a]Variable coding: (1) Runoff/discharge; (2) demand; (3) recharge; (4) glacier change; (5) unmet demand/water availability.

on *robust evidence*, *high agreement*). Rabatel et al. (2013) provides a synthesis of these studies (specific papers are presented in Table 27-3a). Tropical glaciers' retreat has accelerated in the second half of the 20th century (area loss between 20 and 50%), especially since the late 1970s in association with increasing temperature in the same period (Bradley et al., 2009). In early stages of glacier retreat, associated streamflow tends to increase due to an acceleration of glacier melt, but after a peak in streamflow as the glacierized water reservoir gradually empties, runoff tends to decrease, as evidenced in the Cordillera Blanca of Peru (Chevallier et al., 2011; Baraer et al., 2012), where seven out of nine river basins have probably crossed a critical threshold, exhibiting a decreasing dry-season discharge (Baraer et al., 2012). Likewise, glaciers and ice fields in the extratropical Andes located in central-south Chile and Argentina face significant reductions (see review in Masiokas et al. (2009) and details in Table 27-3b), with their effect being compounded by changes in snowpack extent, thus magnifying changes in hydrograph seasonality by reducing flows in dry seasons and increasing them in wet seasons (Pizarro et al., 2013; Vicuña et al., 2013). Central-south Chile and Argentina also face significant reductions in precipitation as shown in Section 27.2.1, contributing to runoff reductions in the last decades of the 20th century (Seoane and López, 2007; Rubio-Álvarez and McPhee, 2010; Urrutia et al., 2011; Vicuña et al., 2013), corroborated with long-term trends found through dendrochronology (Lara et al., 2007; Urrutia et al., 2011). Trends in precipitation and runoff are less evident in the central-north region in Chile (Fiebig-Wittmaack et al., 2012; Souvignet et al., 2012).

As presented in Table 27-4, the assessment of future climate scenarios implications in hydrologic related conditions shows a large range of uncertainty across the spectrum of climate models (mostly using CMIP3 simulations with the exception of Demaria et al. (2013)) and scenarios considered. Nohara et al. (2006) studied climate change impacts on 24 of the main rivers in the world considering a large number of General Circulation Models (GCMs), and found no robust change for the Paraná

(La Plata Basin) and Amazon Rivers. Nevertheless, in both cases the average change showed a positive value consistent, at least with observations for the La Plata Basin. In a more recent work Nakaegawa et al. (2013a) showed a statistically significant increase for both basins in a study that replicated that of Nohara et al. (2006) but with a different hydrologic model. Focusing in extreme flows Guimberteau et al. (2013) show that by the middle of the century no change is found in high flow on the main stem of the Amazon River but there is a systematic reduction in low-flow streamflow. In contrast, the northwestern part of the Amazon River shows a consistent increase in high flow and inundated area (Guimberteau et al., 2013; Langerwisch et al., 2013). On top of such climatic uncertainty, future streamflows and water availability projections are confounded by the potential effects of land use changes (Moore et al., 2007; Coe et al., 2009; Georgescu et al., 2013).

The CA region shows a consistent future runoff reduction. Maurer et al. (2009) studied climate change projections for the Lempa River basin, one of the largest basins in CA, covering portions of Guatemala, Honduras, and El Salvador. They showed that future climate projections (increase in evaporation and reduction in precipitation) imply a reduction of 20% in inflows to major reservoirs in this system (see Table 27-4). Imbach et al. (2012) found similar results using a modeling approach that also considered potential changes in vegetation. These effects could have large hydropower generation implications as discussed in the case study in Section 27.6.1.

The evolution of tropical Andes glaciers associated future climate scenarios has been studied using trend (e.g., Poveda and Pineda, 2009), regression (e.g., Juen et al., 2007; Chevallier et al., 2011), and explicit modeling (e.g., Condom et al., 2012) analysis. These studies indicate that glaciers will continue their retreat (Vuille et al., 2008a) and even disappear as glacier equilibrium line altitude rises, with larger hydrological effects during the dry season (Kaser et al., 2010; Gascoin et al., 2011). This is expected to happen during the next 20 to 50 years (Juen et al., 2007; Chevallier et al., 2011; see Table 27-4). After that period water availability during the dry months is expected to diminish. A projection by Baraer et al. (2012) for the Santa River in the Peruvian Andes finds that once the glaciers are completely melt, annual discharge would decrease by 2 to 30%, depending on the watershed. Glacier retreat can exacerbate current water resources-related vulnerability (Bradley et al., 2006; Casassa et al., 2007; Vuille et al., 2008b; Mulligan et al., 2010), diminishing the mountains' water regulation capacity, making the supply of water for diverse purposes, as well as for ecosystems integrity, more expensive and less reliable (Buytaert et al., 2011). Impacts on economic activities associated with conceptual scenarios of glacier melt reduction have been monetized (Vergara et al., 2007), representing about US$100 million in the case of water supply for Quito, and between US$212 million and US$1.5 billion in the case of the Peruvian electricity sector due to losses of hydropower generation (see the case study in Section 27.6.1). Andean communities will face an important increase in their vulnerability, as documented by Mark et al. (2010), Pérez et al. (2010), and Buytaert and De Bièvre (2012).

In central Chile, Vicuña et al. (2011) project changes in the seasonality of streamflows of the upper snowmelt-driven watersheds of the Limarí River, associated with temperature increases and reductions in water availability owing to a reduction (increase) in precipitation (evapotranspiration). Similar conclusions are derived across the Andes on the Limay River in Argentina by Seoane and López (2007). Under these conditions, semi-arid highly populated basins (e.g., Santiago, Chile) and with extensive agriculture irrigation and hydropower demands are expected to increase their current vulnerability (*high confidence*; ECLAC, 2009a; Souvignet et al., 2010; Fiebig-Wittmaack et al., 2012; Vicuña et al., 2012; see Table 27-4). Projected changes in the cryosphere conditions of the Andes could affect the occurrence of extreme events, such as extreme low and high flows (Demaria et al., 2013), Glacial Lake Outburst Floods (GLOF) occurring in the ice fields of Patagonia (Dussaillant et al., 2010; Marín et al., 2013), volcanic collapse and debris flow associated with accelerated glacial melting in the tropical Andes (Carey, 2005; Carey et al., 2012b; Fraser, 2012), and with volcanoes in southern Chile and Argentina (Tormey, 2010), as well as scenarios of water quality pollution by exposure to contaminants as a result of glaciers' retreat (Fortner et al., 2011).

Another semi-arid region that has been studied thoroughly is northeast Brazil (Hastenrath, 2012). de Mello et al. (2008), Gondim et al. (2008), Souza et al. (2010), and Montenegro and Ragab (2010) have shown that future climate change scenarios would decrease water availability for agriculture irrigation owing to reductions in precipitation and increases in evapotranspiration (*medium confidence*). Krol and Bronstert (2007) and Krol et al. (2006) presented an integrated modeling study that linked projected impacts on water availability for agriculture with economic impacts that could potentially drive full-scale migrations in the NEB region.

27.3.1.2. Adaptation Practices

At an institutional level, a series of policies have been developed to reduce vulnerability to climate variability as faced today in different regions and settings. In 1997, Brazil instituted the National Water Resources Policy and created the National Water Resources Management System under the shared responsibility between the states and the federal government. Key to this new regulation has been the promotion of decentralization and social participation through the creation of National Council of Water Resources and their counterparts in the states, the States Water Resources Councils. The challenges and opportunities dealing with water resources management in Brazil in the face of climate variability and climate change have been well studied (Abers, 2007; Kumler and Lemos, 2008; Medema et al., 2008; Engle et al., 2011; Lorz et al., 2012). Other countries in the region are following similar approaches. In the last years, there have been constitutional and legal reforms toward more efficient and effective water resources management and coordination among relevant actors in Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia, and Mexico; although in many cases, these innovations have not been completely implemented (Hantke-Domas, 2011). Institutional and governance improvements are required to ensure an effective implementation of these adaptation measures (e.g., Halsnæs and Verhagen, 2007; Engle and Lemos, 2010; Lemos et al., 2010; Zagonari, 2010; Pittock, 2011; Kirchhoff et al. 2013).

With regard to region-specific freshwater resources issues it is important to consider adaptation to reduce vulnerabilities in the communities along the tropical Andes and the semi-arid basins in Chile-Argentina, NEB, and the northern CA basins. Different issues have been addressed in

Frequently Asked Questions

FAQ 27.1 | What is the impact of glacier retreat on natural and human systems in the tropical Andes?

The retreat of glaciers in the tropical Andes mountains, with some fluctuations, started after the Little Ice Age (16th to 19th centuries), but the rate of retreat (area reduction between 20 and 50%) has accelerated since the late 1970s. The changes in runoff from glacial retreat into the basins fed by such runoff vary depending on the size and phase of glacier retreat. In an early phase, runoff tends to increase as a result of accelerated melting, but after a peak, as the glacierized water reservoir gradually empties, runoff tends to decrease. This reduction in runoff is more evident during dry months, when glacier melt is the major contribution to runoff (*high confidence*).

A reduction in runoff could endanger high Andean wetlands (bofedales) and intensify conflicts between different water users among the highly vulnerable populations in high-elevation Andean tropical basins. Glacier retreat has also been associated with disasters such as glacial lake outburst floods that are a continuous threat in the region. Glacier retreat could also impact activities in high mountainous ecosystems such as alpine tourism, mountaineering, and adventure tourism (*high confidence*).

assessment of adaptation strategies for tropical Andean communities such as the role of governance and institutions (Young and Lipton, 2006; Lynch, 2012), technology (Carey et al., 2012a), and the dynamics of multiple stressors (McDowell and Hess, 2012; Bury et al., 2013). Semi-arid regions are characterized by pronounced climatic variability and often by water scarcity and related social stress (Krol and Bronstert, 2007; Scott et al., 2012, 2013). Adaptation tools to face the threats of climate change for the most vulnerable communities in the Chilean semi-arid region are discussed by Young et al. (2010) and Debels et al. (2009). In CA, Benegas et al. (2009), Manuel-Navarrete et al. (2007), and Aguilar et al. (2009) provide different frameworks to understand vulnerability and adaptation strategies to climate change and variability in urban and rural contexts, although no specific adaptation strategies are suggested. The particular experience in NEB provides other examples of adaptation strategies to manage actual climate variability. Broad et al. (2007) and Sankarasubramanian et al. (2009) studied the potential benefits of streamflow forecast as a way to reduce the impacts of climate change and climate variability on water distribution under stress conditions. An historical review and analysis of drought management in this region are provided by Campos and Carvalho (2008). de Souza Filho and Brown (2009) studied different water distribution policy scenarios, finding that the best option depended on the degree of water scarcity. The study by Nelson and Finan (2009) provides a critical perspective of drought-related policies, arguing that they constitute an example of maladaptation as they do not try to solve the causes of vulnerability and instead undermine resilience. Tompkins et al. (2008) are also critical of risk reduction practices in this region because they have fallen short of addressing the fundamental causes of vulnerability needed for efficient longer term drought management. Other types of adaptation options that stem from studies on arid and semi-arid regions are related to (1) increase in water supply from groundwater pumping (Döll, 2009; Kundzewicz and Döll, 2009; Zagonari, 2010; Burte et al., 2011; Nadal et al., 2013), fog interception practices (Holder, 2006; Klemm et al., 2012), and reservoirs and irrigation infrastructure (Fry et al., 2010; Vicuña et al., 2010, 2012); and (2) improvements in water demand management associated with increased irrigation efficiency and practices (Geerts et al., 2010; Montenegro and Ragab, 2010; van Oel et al., 2010; Bell et al., 2011; Jara-Rojas et al., 2012) and changes toward less water-intensive crops (Montenegro and Ragab, 2010).

Finally, flood management practices also provide a suite of options to deal with actual and future vulnerabilities related to hydrologic extremes, such as the management of ENSO-related events in Peru via participatory (Warner and Oré, 2006) or risk reduction approaches (Khalil et al., 2007), the role of land use management (Bathurst et al., 2010, 2011; Coe et al., 2011), and flood hazard assessment (Mosquera-Machado and Ahmad, 2006) (*medium confidence*).

27.3.2. Terrestrial and Inland Water Systems

27.3.2.1. Observed and Projected Impacts and Vulnerabilities

CA and SA house the largest biological diversity and several of the world's megadiverse countries (Mittermeier et al., 1997; Guevara and Laborde, 2008). However, land use change has led to the existence of six biodiversity hotspots, that is, places with a great species diversity that show high habitat loss and also high levels of species endemism: Mesoamerica, Chocó-Darien-Western Ecuador, Tropical Andes, Central Chile, Brazilian Atlantic forest, and Brazilian Cerrado (Mittermeier et al., 2005). Thus, conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region (Ayoo, 2008). Tropical deforestation is the second largest driver of anthropogenic climate change on the planet, adding up to 17 to 20% of total greenhouse gas (GHG) emissions during the 1990s (Gullison et al., 2007; Strassburg et al., 2010). In parallel, the region still has large extensions of wilderness areas for which the Amazon is the most outstanding example. Nevertheless, some of these areas are precisely the new frontier of economic expansion. For instance, between 1996 and 2005, Brazil deforested about 19,500 $km^2\ yr^{-1}$, which represented 2 to 5% of global annual carbon dioxide (CO_2) emissions (Nepstad et al., 2009). Between 2005 and 2009, deforestation in the Brazilian Amazon dropped by 36%, which is partly related to the network of protected areas that now covers around 45.6% of the biome in Brazil (Soares-Filho et al., 2010). Using the LandSHIFT modeling framework for land use change and the IMPACT projections of crop/livestock production, Lapola et al. (2011) projected that zero deforestation in the Brazilian Amazon forest by 2020 (and of the Cerrado by 2025) would require either a reduction of 26 to 40% in livestock production until 2050 or a doubling of average livestock density from 0.74 to 1.46 head per hectare. Thus, climate change may imply reduction of yields and entail further deforestation.

Local deforestation rates or rising GHGs globally drive changes in the regional SA that during this century might lead the Amazon rainforest into crossing a critical threshold at which a relatively small perturbation can qualitatively alter the state or development of a system (Cox et al., 2000; Salazar et al., 2007; Sampaio et al., 2007; Lenton et al., 2008; Nobre and Borma, 2009). Various models are projecting a risk of reduced rainfall and higher temperatures and water stress, which may lead to an abrupt and irreversible replacement of Amazon forests by savanna-like vegetation, under a high emission scenario (A2), from 2050–2060 to 2100 (Betts et al., 2004, 2008; Cox et al., 2004; Salazar et al., 2007; Sampaio et al., 2007; Malhi et al., 2008, 2009; Sitch et al., 2008; Nobre and Borma, 2009; Marengo et al., 2011c). The possible "savannization" or "die-back" of the Amazon region would potentially have large-scale impacts on climate, biodiversity, and people in the region. The possibility of this die-back scenario occurring, however, is still an open issue and the uncertainties are still very high (Rammig et al., 2010; Shiogama et al., 2011).

Plant species are rapidly declining in CA, SA, Central and West Africa, and Southeast Asia (Bradshaw et al., 2009). Risk estimates of plant species extinction in the Amazon, which do not take into account possible climate change impacts, range from 5 to 9% by 2050 with a habitat reduction of 12 to 24% (Feeley and Silman, 2009) to 33% by 2030 (Hubbell et al., 2008). The highest percentage of rapidly declining amphibian species occurs in CA and SA. Brazil is among the countries with most threatened bird and mammal species (Bradshaw et al., 2009).

A similar scenario is found in inland water systems. Among components of aquatic biodiversity, fish are the best-known organisms (Abell et al., 2008), with Brazil accounting for the richest icthyofauna of the planet (Nogueira et al., 2010). For instance, the 540 Brazilian small microbasins host 819 fish species with restrict distribution. However, 29% of these microbasins have historically lost more than 70% of their natural vegetation cover and only 26% show a significant overlap with protected areas or indigenous reserves. Moreover, 40% of the microbasins overlap with hydrodams (see Section 27.6.1 and Chapter 3) or have few protected areas and high rates of habitat loss (Nogueira et al., 2010).

The faster and more severe the rate of climate change, the more severe the biological consequences such as species decline (Brook et al., 2008). Vertebrate fauna in North and South America is projected to suffer species losses until 2100 of at least 10%, as forecasted in more than 80% of the climate projections based on a low-emissions scenario (Lawler et al., 2009). Vertebrate species turnover until 2100 will be as high as 90% in specific areas of CA and the Andes Mountains for emission scenarios varying from low B1 to mid-high A2 (Lawler et al., 2009). Elevational specialists, that is, a small proportion of species with small geographic ranges restricted to high mountains, are most frequent in the Americas (e.g., Andes and Sierra Madre) and might be particularly vulnerable to global warming because of their small geographic ranges and high energetic and area requirements, particularly birds and mammals (Laurance et al., 2011). In Brazil, projections for Atlantic forest birds (Anciães and Peterson, 2006), endemic bird species (Marini et al., 2009), and plant species (by 2055, scenarios HHGSDX50 and HHGGAX50; Siqueira and Peterson, 2003) of the Cerrado indicate that distribution will dislocate toward the south and southeast, precisely where fragmentation and habitat loss are worse. Global climate change is also predicted to increase negative impacts worldwide, including SA, on freshwater fisheries due to alterations in physiology and life histories of fish (Ficke et al., 2007).

In addition to climate change impacts at the individual species level, biotic interactions will be affected. Modifications in phenology, structure of ecological networks, predator-prey interactions, and non-trophic interactions among organisms have been forecasted (Brooker et al., 2008; Walther, 2010). The outcome of non-trophic interactions among plants is expected to shift along with variation in climatic parameters, with more facilitative interactions in more stressful environments, and more competitive interactions in more benign environments (Brooker et al., 2008; Anthelme et al., 2012). These effects are expected to have a strong influence of community and ecosystem (re-)organization given the key engineering role played by plants on the functioning of ecosystems (Callaway, 2007). High Andean ecosystems, especially those within the tropics, are expected to face exceptionally strong warming effects during the 21st century because of their uncommonly high altitude (Bradley et al., 2006). At the same time they provide a series of crucial ecosystem services for millions of people (Buytaert et al., 2011). For these reasons shifts in biotic interactions are expected to have negative consequences on biodiversity and ecosystem services in this region.

Although in the region biodiversity conservation is largely confined to protected areas, with the magnitude of climatic changes projected for the century, it is expected that many species and vegetational types will lose representativeness inside such protected areas (Heller and Zavaleta, 2009).

27.3.2.2. Adaptation Practices

The subset of practices that are multi-sectoral, multi-scale, and based on the premise that ecosystem services reduce the vulnerability of society to climate change are known as Ecosystem-based Adaptation (EbA; Vignola et al., 2009; see Glossary and Box CC-EA). Schemes such as the payment for environmental services (PES) and community management fit the concept of EbA that begins to spread in CA and SA (Vignola et al., 2009). The principle behind these schemes is the valuation of ecosystem services that should reflect both the economic and cultural benefits derived from the human-ecosystem interaction and the capacity of ecosystems to secure the flow of these benefits in the future (Abson and Termansen, 2011).

Because PES schemes have developed more commonly in CA and SA than in other parts of the world (Balvanera et al., 2012), this topic will be covered as a case study (see Section 27.6.2).

Ecological restoration, conservation in protected areas, and community management can all be important tools for adaptation. A meta-analysis of 89 studies by Benayas et al. (2009) (with a time scale of restoration varying from <5 to 300 years), including many in SA, showed that ecological restoration enhances the provision of biodiversity and environmental services by 44 and 25%, respectively, as compared to degraded systems. Moreover, ecological restoration increases the potential for carbon sequestration and promotes community organization, economic activities, and livelihoods in rural areas (Chazdon, 2008), as seen in examples of the Brazilian Atlantic Forest (Calmon et al., 2011; Rodrigues et al., 2011). In that sense, Locatelli et al. (2011) revised several ecosystem conservation and restoration initiatives in CA and SA that simultaneously help mitigate and adapt to climate change. Chazdon et al. (2009) also highlight the potential of restoration efforts to build ecological corridors (see Harvey et al., 2008, for an example in Central America).

The effective management of natural protected areas and the creation of new protected areas within national protected area systems and community management of natural areas are also efficient tools to adapt to climate change and to reconcile biodiversity conservation with socioeconomic development (e.g., Bolivian Andes: Hoffmann et al., 2011; Panama: Oestreicher et al., 2009). Porter-Bolland et al. (2012) compared protected areas with areas under community management in different parts of the tropical world, including CA and SA, and found that protected areas have higher deforestation rates than areas with community management. Similarly, Nelson and Chomitz (2011) found for the region that (1) protected areas of restricted use reduced fire substantially, but multi-use protected areas are even more effective; and (2) in indigenous reserves the incidence of forest fire was reduced by 16% as compared to non-protected areas. This contrasts with the findings of Miteva et al. (2012), who found protected areas more efficient in constraining deforestation than other schemes. Other good examples of adaptive community management in the continent include community forest concessions (e.g., Guatemala: Radachowsky et al., 2012), multiple-use management of forests (Guariguata et al., 2012; see also examples in Brazil: Klimas et al., 2012, Soriano et al., 2012, and Bolivia: Cronkleton et al., 2012); and local communities where research and monitoring protocols are in place to pay the communities for collecting primary scientific data (Luzar et al., 2011).

27.3.3. Coastal Systems and Low-Lying Areas

27.3.3.1. Observed and Projected Impacts and Vulnerabilities

Climate change is altering coastal and marine ecosystems (Hoegh-Guldberg and Bruno, 2010). Coral reefs (Chapter 5; Box CC-CR), seagrass beds, mangroves, rocky reefs and shelves, and seamounts have few to no areas left in the world that remain unaffected by human influence (Halpern et al., 2008). Anthropogenic drivers associated with climate change decreased ocean productivity, altered food web dynamics, reduced the abundance of habitat-forming species, shifted species distributions, and led to a greater incidence of disease (Hoegh-Guldberg and Bruno, 2010). Coastal and marine impacts and vulnerability are often associated with collateral effects of climate change such as SLR, ocean warming, and ocean acidification (Box CC-OA). Overfishing, habitat pollution and destruction, and the invasion of species also negatively impact biodiversity and the delivery of ecosystem services (Guarderas et al., 2008; Halpern et al., 2008). Such negative impacts lead to losses that pose significant challenges and costs for societies, particularly in developing countries (Hoegh-Guldberg and Bruno, 2010). For instance, the Ocean Health Index (Halpern et al., 2012), which measures how healthy the coupling of the human-ocean system is for every coastal country (including parameters related to climate change), indicates that CA countries rank among the lowest values. For SA, Suriname stands out with one of the highest scores.

Coastal states of LA and the Caribbean have a human population of more than 610 million, three-fourths of whom live within 200 km of the coast (Guarderas et al., 2008). For instance, studying seven countries in the region (El Salvador, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Ecuador), Lacambra and Zahedi (2011) found that more than 30% of the population lives in coastal areas directly exposed to climatic events. Large coastal populations are related to the significant transformation marine ecosystems have been undergoing in the region. Fish stocks, places for recreation and tourism, and controls of pests and pathogens are all under pressure (Guarderas et al., 2008; Mora, 2008). Moreover, SLR varied from 2 to 7 mm yr^{-1} between 1950 and 2008 in CA and SA. The Western equatorial border, influenced by the ENSO phenomenon, shows a lower variation (of about 1 mm yr^{-1}) and a range of variation under El Niño events of the same order of magnitude that sustained past changes (Losada et al., 2013). The distribution of population is a crucial factor for inundation impact, with coastal areas being non-homogeneously impacted. A scenario of 1 m SLR would affect some coastal populations in Brazil and the Caribbean islands (see Figure 27-6; ECLAC, 2011a).

27.3.3.1.1. Coastal impacts

Based on trends observed and projections, Figure 27-6 shows how potential impacts may be distributed in the region. (a) *Flooding*: Since flooding probability increases with increasing sea level, one may expect a higher probability of flooding in locations showing >40% of change over the last 60 years in the 100-years total sea level (excluding hurricanes). The figure also identifies urban areas where the highest increase in flooding level has been obtained. (b) *Beach erosion*: It increases with potential sediment transport, thus locations where changes in potential sediment transport have increased over a certain threshold have a higher probability to be eroded. (c) *Sea ports and reliability of coastal structures*: The figure shows locations where, in the case of having a protection structure in place, there is a reduction in the reliability of the structures owing to the increase in the design wave height estimates (ECLAC, 2011a).

27.3.3.1.2. Coastal dynamics

Information on coastal dynamics is based on historical time series that have been obtained by a combination of data reanalysis, available instrumental information, and satellite information. Advanced statistical techniques have been used for obtaining trends including uncertainties (Izaguirre et al., 2013; Losada et al., 2013).

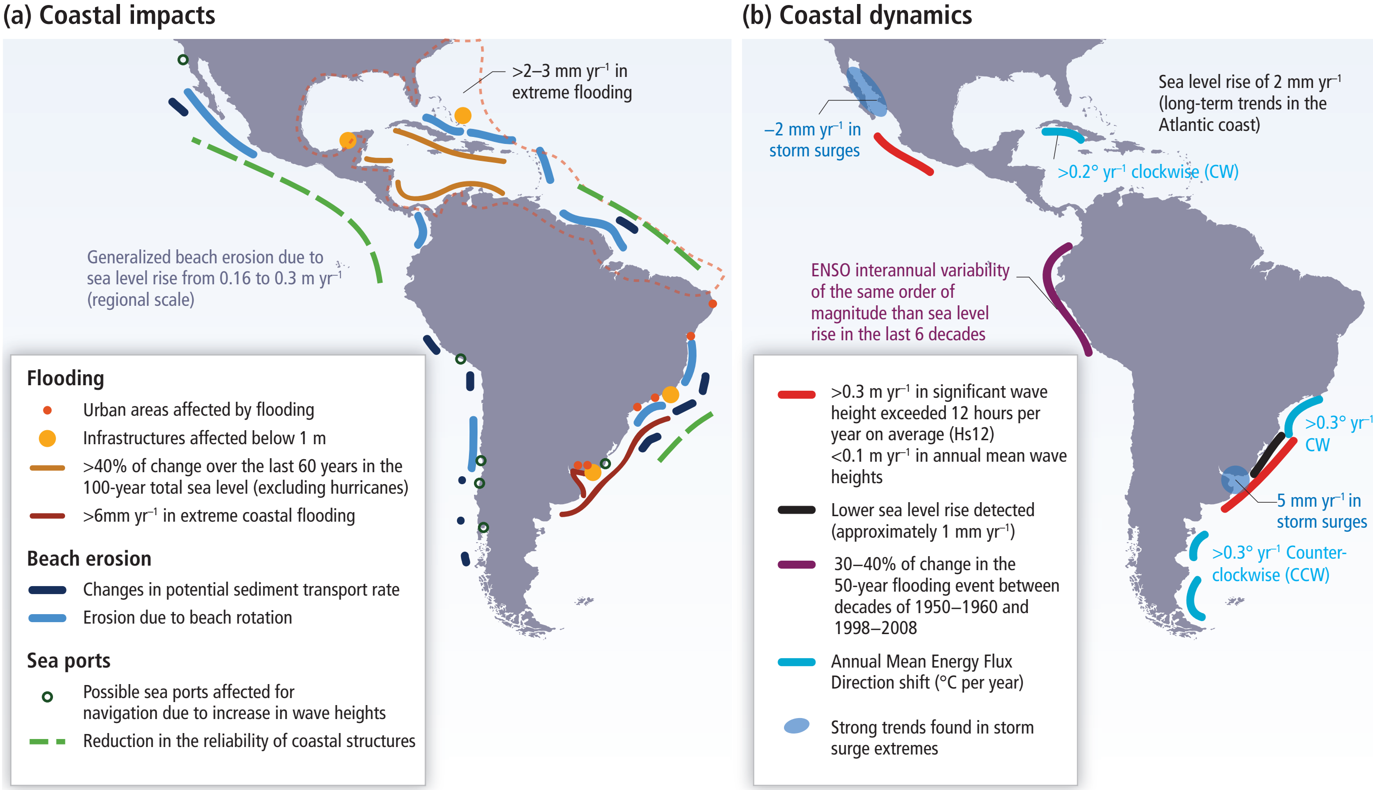

Figure 27-6 | Current and predicted coastal impacts (a) and coastal dynamics (b) in response to climate change. (a) Coastal impacts: Based on trends observed and projections, the figure shows how potential impacts may be distributed in the region (ECLAC, 2011a). ***Flooding***: Since flooding probability increases with increasing sea level, one may expect a higher probability of flooding in locations showing >40% of change over the last 60 years in 100-year total sea level (excluding hurricanes). The figure also identifies urban areas where the highest increase in flooding level has been obtained. ***Beach erosion***: Increases with potential sediment transport, and thus locations where changes in potential sediment transport have increased over a certain threshold have a higher probability of being eroded. ***Sea ports and reliability of coastal structures***: Shows locations where, in the case of having a protection structure in place, there is a reduction in the reliability of the structures due to the increase in the design wave height estimates. (b) Coastal dynamics: Information based on historical time series that have been obtained by a combination of data reanalysis, available instrumental information, and satellite information. Advanced statistical techniques have been used for obtaining trends including uncertainties (Izaguirre et al., 2013; Losada et al., 2013).

The greatest flooding levels (hurricanes not considered) in the region are found in Rio de La Plata area, which combine a 5 mm yr^{-1} change in storm surge with SLR changes in extreme flooding levels (ECLAC, 2011a; Losada et al., 2013). Extreme flooding events may become more frequent because return periods are decreasing, and urban coastal areas in the eastern coast will be particularly affected, while at the same time beach erosion is expected to increase in southern Brazil and in scattered areas at the Pacific coast (ECLAC, 2011a).

The majority of the literature concerning climate change impacts for coastal and marine ecosystems considers coral reefs (see also Chapter 5; Box CC-CR), mangroves, and fisheries. Coral reefs are particularly sensitive to climate-induced changes in the physical environment (Baker et al., 2008) to an extent that one-third of the more than 700 species of reef-building corals worldwide are already threatened with extinction (Carpenter et al., 2008). Coral bleaching and mortality are often associated with ocean warming and acidification (Baker et al., 2008). If extreme sea surface temperatures were to continue, the projections using SRES scenarios (A1FI, 3°C sensitivity, and A1B with 2°C and 4.5°C sensitivity) indicate that it is possible that the Mesoamerican coral reef will collapse by mid-century (between 2050 and 2070), causing major economic losses (Vergara, 2009). Extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of CA and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras, and Guatemala (Eakin et al., 2010). Reef and also mangrove ecosystems are estimated to contribute greatly to goods and services in economic terms. In Belize, for example, this amount is approximately US$395 to US$559 million annually, primarily through marine-based tourism, fisheries, and coastal protection (Cooper et al., 2008). In the Eastern Tropical Pacific, seascape trace abundance of cement and elevated nutrients in upwelled waters are factors that help explain high bioerosion rates of local coral reefs (Manzello et al., 2008). In the southwestern Atlantic coast, eastern Brazilian reefs might suffer a massive coral cover decline in the next 50 years (Francini-Filho et al., 2008). This estimate is based on coral disease prevalence and progression rate, along with growth rate of *Mussismilia braziliensis*—a major reef-building coral species that is endemic in Brazil. These authors also pointed out that coral diseases intensified between 2005 and 2007 based on qualitative observations since the 1980s and regular monitoring since 2001. They have also predicted that the studied coral species will be nearly extinct in less than a century if the current rate of mortality due to disease is not reversed.

Mangroves are largely affected by anthropogenic activities whether or not they are climate driven. All mangrove forests, along with important ecosystem goods and services, could be lost in the next 100 years if the present rate of loss continues (1 to 2% a year; Duke et al., 2007). Moreover, estimates are that climate change may lead to a maximum global loss of 10 to 15% of mangrove forest by 2100 (Alongi, 2008). In CA and SA, some of the main drivers of loss are deforestation and land conversion, agriculture, and shrimp ponds (Polidoro et al., 2010). The Atlantic and Pacific coasts of CA are some of the most endangered on the planet with regard to mangroves, as approximately 40% of present species are threatened with extinction (Polidoro et al., 2010). Approximately 75% of the global mangrove extension is concentrated in 15 countries, among which Brazil is included (Giri et al., 2011). The rate of survival of original mangroves lies between 12.8 and 47.6% in the Tumaco Bay (Colombia), resulting in ecosystem collapse, fisheries reduction, and impacts on livelihoods (Lampis, 2010). Gratiot et al. (2008) project for the current decade an increase of mean high water levels of 6 cm followed by 90 m shoreline retreat, implying flooding of thousands of hectares of mangrove forest along the coast of French Guiana.

Peru and Colombia are two of the eight most vulnerable countries to climate change impacts on fisheries, owing to the combined effect of observed and projected warming, to species and productivity shifts in upwelling systems, to the relative importance of fisheries to national economies and diets, and limited societal capacity to adapt to potential impacts and opportunities (Allison et al., 2009). Fisheries production systems are already pressured by overfishing, habitat loss, pollution, invasive species, water abstraction, and damming (Allison et al., 2009). In Brazil, a decadal rate of 0.16 trophic level decline (as measured by the Marine Trophic Index, which refers to the mean trophic level of the catch) has been detected through most of the northeastern coast, between 1978 and 2000, which is one of the highest rates documented in the world (Freire and Pauly, 2010).

Despite the focus in the literature on corals, mangroves, and fisheries, there is evidence that other benthic marine invertebrates that provide key services to reef systems, such as nutrient cycling, water quality regulation, and herbivory, are also threatened by climate change (Przeslawski et al., 2008). The same applies for seagrasses, for which a worldwide decline has accelerated from a median of 0.9% yr^{-1} before 1940 to 7% yr^{-1} since 1990, which is comparable to rates reported for mangroves, coral reefs, and tropical rainforests, and place seagrass meadows among the most threatened ecosystems on earth (Waycott et al., 2009).

A major challenge of particular relevance at local and global scales will be to understand how these physical changes will impact the biological environment of the ocean (e.g., Gutiérrez et al., 2011b), as the Humboldt Current system—flowing along the west coast of SA—is the most productive upwelling system of the world in terms of fish productivity.

27.3.3.2. Adaptation Practices

Designing marine protected areas (MPAs) that are resilient to climate change is a key adaptation strategy in coastal and marine environments (McLeod et al., 2009). By 2007, LA and the Caribbean (which includes CA and SA countries) had more than 700 MPAs established covering around 1.5% of the coastal and shelf waters, most of which allow varying levels of extractive activities (Guarderas et al., 2008). This protected area cover, however, is insufficient to preserve important habitats or connectivity among populations at large biogeographic scales (Guarderas et al., 2008).

Nevertheless, examples of adaptation in CA and SA are predominantly related to MPAs. In Brazil, a protected area type known as "Marine Extractive Reserves" currently benefits 60,000 small-scale fishermen along the coast (de Moura et al., 2009). Examples of fisheries' co-management, a form of a participatory process involving local fishermen communities, government, academia, and non-governmental organizations, are reported to favor a balance between conservation of marine fisheries, coral reefs, and mangroves on the one hand (Francini-Filho and de Moura, 2008), and the improvement of livelihoods, as well as the cultural survival of traditional populations on the other (de Moura et al., 2009; Hastings, 2011).

Significant financial and human resources are expended annually in the marine reserves to support reef management efforts. These actions, including the creation of marine reserves to protect from overfishing, improvement of watershed management, and protection or replanting of

Frequently Asked Questions

FAQ 27.2 | Can payment for ecosystem services be used as an effective way to help local communities adapt to climate change?

Ecosystems provide a wide range of basic services, such as providing breathable air, drinkable water, and moderating flood risk (*very high confidence*). Assigning values to these services and designing conservation agreements based on these (broadly known as payment for ecosystem services, or PES) can be an effective way to help local communities adapt to climate change. It can simultaneously help protect natural areas and improve livelihoods and human well-being (*medium confidence*). However, during design and planning, a number of factors need to be taken into consideration at the local level to avoid potentially negative results. Problems can arise if (1) the plan sets poor definitions about whether the program should focus just on actions to be taken or the end result of those actions, (2) many perceive the initiative as commoditization of nature and its intangible values, (3) the action is inefficient to reduce poverty, (4) difficulties emerge in building trust between various stakeholders involved in agreements, and (5) there are eventual gender or land tenure issues.

coastal mangroves, are proven tools to improve ecosystem functioning. In Mesoamerican reefs Carilli et al. (2009) found out that such actions may also actually increase the thermal tolerance of corals to bleaching stress and thus the associated likelihood of surviving future warming.

In relation to mangroves, in addition to marine protected areas that include mangroves and functionally linked ecosystems, Gilman et al. (2008) list a number of other relevant adaptation practices: coastal planning to facilitate mangrove migration with SLR, management of activities within the catchment that affect long-term trends in the mangrove sediment elevation, better management of non-climate stressors, and the rehabilitation of degraded areas. However, such types of practices are not frequent in the region.

On the other hand, the implementation of adaptation strategies to SLR or to address coastal erosion is more commonly seen in many countries in the region (Lacambra and Zahedi, 2011). For instance, redirecting new settlements to better-protected locations and to promote investments in appropriate infrastructure shall be required in the low elevation coastal zones (LECZ) of the region, particularly in lower income countries with limited resources, which are especially vulnerable. The same applies to countries with high shares of land (e.g., Brazil ranking 7th worldwide of the total land area in the LECZ) and/or population (e.g., Guyana and Suriname ranking 2nd and 5th by the share of population in the LECZ, having respectively 76 and 55% of their populations in such areas) (McGranahan et al., 2007). Adaptation will demand effective and enforceable regulations and economic incentives, all of which require political will as well as financial and human capital (McGranahan et al., 2007). Adaptive practices addressing river flooding are also being made available as in the study of Casco et al. (2011) for the low Paraná River in Argentina (see also Chapters 5 and 6 for coastal and marine adaptation).

27.3.4. Food Production Systems and Food Security

27.3.4.1. Observed and Projected Impacts and Vulnerabilities

Increases in the global demand for food and biofuels promoted a sharp increase in agricultural production in SA and CA, associated mainly with the expansion of planted areas (see Chapter 7), and this trend is predicted to continue in the future (see Section 27.2.2.1). Ecosystems are being and will be affected in isolation and synergistically by climate variability/change and land use changes, which are comparable drivers of environmental change (see Sections 27.2.2.1, 27.3.2.1). By the end of the 21st century (13 GCMs, under SRES A1B and B1) SA could lose between 1 and 21% of its arable land due to climate change and population growth (Zhang and Cai, 2011).

Optimal land management could combine efficient agricultural and biofuels production with ecosystem preservation under climate change. However, current practices are leading to a deterioration of ecosystems throughout the continent (see Section 27.3.2). In southern Brazilian Amazonia water yields (mean daily discharge (mm d^{-1})) were near four times higher in soy than in forested watersheds, and showed greater seasonal variability (Hayhoe et al., 2011). In the Argentinean Pampas current land use changes disrupt water and biogeochemical cycles and may result in soil salinization, altered carbon and nitrogen storage, surface runoff, and stream acidification (Nosetto et al., 2008; Berthrong et al., 2009; Farley et al., 2009). In central Argentina flood extension was associated with the dynamics of groundwater level, which has been influenced by precipitation and land use change (Viglizzo et al., 2009).

27.3.4.1.1. Observed impacts

The SESA region has shown significant increases in precipitation and wetter soil conditions during the 20th century (Giorgi, 2002; see Table 27-1) that benefited summer crops and pastures productivity, and contributed to the expansion of agricultural areas (Barros, 2008a; Hoyos et al., 2012). Wetter conditions observed during 1970–2000 (in relation to 1930–1960) led to increases in maize and soybean yields (9 to 58%) in Argentina, Uruguay, and southern Brazil (Magrin et al., 2007b). Even if rainfall projections estimate increases of about 25% in SESA for 2100, agricultural systems could be threatened if climate reverts to a drier situation due to inter-decadal variability. This could put at risk the viability of continuous agriculture in marginal regions of Argentina's Pampas (Podestá et al., 2009). During the 1930s and 1940s, dry and windy conditions together with deforestation, overgrazing, overcropping, and non-suitable tillage produced severe dust storms, cattle mortality, crop failure, and rural migration (Viglizzo and Frank, 2006).

At the global scale (see Chapter 7), warming since 1981 has reduced wheat, maize, and barley productivity, although the impacts were small compared with the technological yield gains over the same period (Lobell and Field, 2007). In central Argentina, simulated potential wheat yield—without considering technological improvements—has been decreasing at increasing rates since 1930 (1930–2000: –28 kg ha^{-1} yr^{-1}; 1970–2000: –53 kg ha^{-1} yr^{-1}) in response to increases in minimum temperature during October–November (1930–2000: +0.4°C per decade; 1970–2000: +0.6°C per decade) (Magrin et al., 2009). The observed changes in the growing season temperature and precipitation between 1980 and 2008 have slowed the positive yield trends due to improved genetics in Brazilian wheat, maize, and soy, as well as Paraguayan soy. In contrast, rice in Brazil and soybean in Argentina have benefited from precipitation and temperature trends (Lobell et al., 2011). In Argentina, increases in soybean yield may be associated with weather types that favor the entry of cold air from the south, reducing thermal stress during flowering and pod set, and weather types that increase the probability of dry days at harvest (Bettolli et al., 2009).

27.3.4.1.2. Projected impacts

Assessment of future climate scenarios implications to food production and food security (see Table 27-5) shows a large range of uncertainty across the spectrum of climate models and scenarios. One of the uncertainties is related to the effect of CO_2 on plant physiology. Many crops (such as soybean, common bean, maize, and sugarcane) can probably respond with an increasing productivity as a result of higher growth rates and better water use efficiency. However, food quality could decrease as a result of higher sugar contents in grain and fruits, and decreases in the protein content in cereals and legumes (DaMatta et al., 2010). Uncertainties associated with climate and crop models, as well as with the uncertainty in human behavior, potentially lead to large error bars on any long-term prediction of food output. However, the trends presented here represent the current available information.

In SESA, some crops could be benefitted until mid-21st century if CO_2 effects are considered (see Table 27-5), although interannual and decadal climate variability could provoke important damages. In Uruguay and Argentina, productivity could increase or remain almost stable until the 2030s–2050s depending on the SRES scenario (ECLAC, 2010c). Warmer and wetter conditions may benefit crops toward the southern and western zone of the Pampas (Magrin et al., 2007c; ECLAC, 2010c). In south Brazil, irrigated rice yield (Walter et al., 2010) and bean productivity (Costa et al., 2009) are expected to increase. If technological improvement is considered, the productivity of common bean and maize could increase

Table 27-5 | Impacts on agriculture.

Country/region		Activity	Time slice	Special report on Emissions Scenarios (SRES)	CO_2	Changes	Source
Southeastern South America	Uruguay	Annual crops	2030/2050/2070/2100	A2		+185/–194/–284/–508	ECLAC (2010a)[1]
			2030/2050	B2		+92/+169	
		Livestock	2030/2050/2070/2100	A2		+174/–80/–160/–287	
			2030/2050	B2		+136/+182	
		Forestry	2030/2050/2070/2100	A2		+15/+39/+52/+19	
			2030/2050/2070	B2		+6/+13/+18	
	Paraguay	Cassava	2020/2050/2080	A2		+16/+22/+22	ECLAC (2010a)
		Wheat	2020/2050/2080	A2		+4/–9/–13	
				B2		–1/+1/–5	
		Maize	2020/2050/2080	A2		+3/+3/+8	
				B2		+3/+1/+6	
		Soybean	2020/2050/2080	A2		0/–10/–15	
				B2		0/–15/–2	
		Bean	2020/2050/2080	A2		–1/+10/+16	
	Argentina	Maize	2080	A2/B2	N	–24/–15	ECLAC (2010a)
				A2/B2	Y	+1/0	
		Soybean	2080	A2/B2	N	–25/–14	
				A2/B2	Y	+14/+19	
		Wheat	2080	A2/B2	N	–16/–11	
				A2/B2	Y	+3/+3	
		Soybean	2020/2050/2080	A2	Y	+24/+42/+48	Travasso et al. (2008)
				B2	Y	+14/+30/+33	
		Maize	2020/2050/2080	A2	Y	+8/+11/+16	
				B2	Y	+5/+5/+9	
	Brazil	Rice		$2CO_2$/0ºC	Y	+60	Walter et al. (2010)
				$2CO_2$/+5ºC	Y	+30	
		Bean	2050/2080	A2	N	Up to –30%	Costa et al. (2009)[2]
			2020/2050/2080	A2+CO_2	Y	Up to: +30/+30/+45	
				A2+CO_2+T	Y	Up to: +45/+75/+90	
		Maize	2050/2080	A2	N	Up to –30%	
				A2+CO_2	Y	Near to –15%	
			2020/2050/2080	A2+CO_2+T	Y	Up to: +40/+60/+90	
		Arabica coffee		+0 to +1ºC		+1.5%	Zullo et al. (2011)[3]
				+1 to +2ºC		+15.9%	
				+2 to +3ºC		+28.6%	
				+3 to +4ºC		–12.9%	
State of São Paulo, Brazil		Sugarcane	2040	Pessimistic		+6%	Marin et al. (2009)
				Optimistic		+2%	

Continued next page →

between 40 and 90% (Costa et al., 2009). Sugarcane production could benefit, as warming could allow the expansion of planted areas toward the south, where low temperatures are a limiting factor (Pinto et al., 2008). Increases in crop productivity could reach 6% in São Paulo state toward 2040 (Marin et al., 2009). In Paraguay the yields of soybean, maize, and wheat could have slight variations (–1.4 to +3.5%) until 2020 (ECLAC, 2010a).

In Chile and western Argentina, yields could be reduced by water limitation. In central Chile (30ºS to 42ºS) temperature increases, reduction in chilling hours, and water shortages may reduce productivity of winter crops, fruits, vines, and radiata pine. Conversely, rising temperatures, more moderate frosts, and more abundant water will *very likely* benefit all species toward the south (ECLAC, 2010a; Meza and da Silva, 2009). In northern Patagonia (Argentina) fruit and vegetable growing could be negatively affected because of a reduction in rainfall and in average flows in the Neuquén River basin. In the north of the Mendoza basin (Argentina) increases in water demand, due to population growth, may compromise the availability of subterranean water for irrigation, pushing up irrigation costs and forcing many producers out of farming toward 2030. Also, water quality could be reduced by the worsening of existing salinization processes (ECLAC, 2010a).

In CA, NEB, and parts of the Andean region (Table 27-5) climate change could affect crop yields, local economies, and food security. It is *very likely* that growing season temperatures in parts of tropical SA, east of the Andes, and CA exceed the extreme seasonal temperatures documented from 1900 to 2006 at the end of this century (23 GCMs), affecting regional agricultural productivity and human welfare (Battisti and Naylor, 2009). For NEB, declining crop yields in subsistence crops such as beans,

Table 27-5 (continued)

Country/region	Activity	Time slice	Special report on Emissions Scenarios (SRES)	CO_2	Changes	Source
Northeastern Brazil	Cassava	2020–2040		N	0 to –10	Lobell et al. (2008)
	Maize	2020–2040		N	0 to –10	
	Rice	2020–2040		N	–1 to –10	
	Wheat	2020–2040		N	–1 to –14	
	Maize				–20 to –30	Margulis et al. (2010)
	Bean				–20 to –30	
	Rice				–20 to –30	
	Cowpea bean		+1.5ºC		–26%	Silva et al. (2010)[3]
			+3.0ºC		–44%	
			+5.0ºC		–63%	
Central America	Maize	2030/2050/2070/2100	A2		0/0/–10/–30	ECLAC (2010a)
	Bean	2030/2050/2070/2100	A2		–4/–19/–29/–87	
	Rice	2030/2050/2070/2100	A2		+3/–3/–14/–63	
	Rice	2020–2040		N	0 to –10	Lobell et al. (2008)
	Wheat	2020–2040		N	–1 to –9	
Panamá	Maize	2020/2050/2080	A2	Y	–0.5/+2.4/+4.5	Ruane et al. (2011)
			B1	Y	–0.1/–0.8/+1.5	
Andean Region	Wheat	2020–2040		N	–14 to +2	Lobell et al. (2008)
	Barley	2020–2040		N	0 to –13	
	Potato	2020–2040		N	0 to –5	
	Maize	2020–2040		N	0 to –5	
Colombia	All main crops	2050	17 GCMs (A2)		80% of crops impacted in more than 60% of current cultivated areas	Ramirez et al. (2012)
Chile (34.6º to 38.5ºS)	Maize	2050	A1FI	Y	–5% to –10%	Meza and Silva (2009)
	Wheat	2050	A1FI	Y	–10% to –20%	

Notes:
Changes are expressed as differences in relative yield (%), except for [1] and [3].

N: Without considering CO_2 biological effects.
Y: Considering CO_2 biological effects.
$2CO_2$: Considering double CO_2 concentration (780 ppm CO_2).
T: Considering technological improvement (genetic changes).

[1]Gross value of production (millions of US$).
[2]Huge spatial variability; values are approximated.
[3]Changes in the percentage of areas with low climate risk.

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corn, and cassava are projected (Lobell et al., 2008; Margulis et al., 2010). In addition, increases in temperature could reduce the areas currently favorable to cowpea bean (Silva et al., 2010). The highest warming foreseen for 2100 (5.8°C, under SRES A2 scenario) could make the coffee crop unfeasible in Minas Gerais and São Paulo (southeast Brazil) if no adaptation action is accomplished. Thus, the coffee crop may have to be transferred to southern regions where temperatures are lower and the frost risk will be reduced (Camargo, 2010). With +3ºC, Arabica coffee is expected to expand in the extreme south of Brazil, the Uruguayan border, and northern Argentina (Zullo Jr. et al., 2011). Brazilian potato production could be restricted to a few months in currently warm areas, which today allow potato production year-round (Lopes et al., 2011). Large losses of suitable environments for the "Pequi" tree (*Caryocar brasiliense*, an economically important Cerrado fruit tree) are projected by 2050, affecting mainly the poorest communities in central Brazil (Nabout et al., 2011). In the Amazon region soybean yields would be reduced by 44% in the worst scenario (Hadley Centre climate prediction model 3 (HadCM3) and no CO_2 fertilization) by 2050 (Lapola et al., 2011). By 2050, according to 17 GCMs under SRES A2 scenario, 80% of crops will be impacted in more than 60% of current areas of cultivation in Colombia, with severe impacts in perennial and exportable crops (Ramirez-Villegas et al., 2012).

Teixeira et al. (2013) identified hotspots for heat stress toward 2071–2100 under the A1B scenario and suggest that rice in southeast Brazil, maize in CA and SA, and soybean in central Brazil will be the crops and zones most affected by increases in temperature.

In CA, changes projected in climate could severely affect the poorest population and especially their food security, increasing the current rate of chronic malnutrition. Currently, Guatemala is the most food insecure country by percentage of the population (30.4%) and the problem has been increasing in recent years (FAO, WFP, and IFAD, 2012). The impact of climate variability and change is a great challenge in the region. As an example, the recent rust problem on the coffee sector of 2012–2013 has affected nearly 600,000 ha (55% of the total area) (ICO, 2013) and will reduce employment by 30 to 40% for the harvest 2013–2014 (FEWS NET, 2013). At least 1.4 million people in Guatemala, El Salvador, Honduras, and Nicaragua depend on the coffee sector, which is very susceptible to climate variations. In Panamá, the large interannual climate variability will continue to be the dominant influence on seasonal maize yield into the coming decades (Ruane et al., 2013). In the future, warming conditions combined with more variable rainfall are expected to reduce maize, bean, and rice productivity (ECLAC, 2010c); rice and wheat yields could decrease up to 10% by 2030 (Lobell et al., 2008; *medium confidence*). In CA, nearly 90% of agricultural production destined for internal consumption is composed by maize (70%), bean (25%), and rice (6%) (ECLAC, 2011d).

Climate change may also alter the current scenario of plant diseases and their management, having effects on productivity (Ghini et al., 2011). In Argentina, years with severe infection of late cycle diseases in soybean could increase; severe outbreaks of the Mal de Rio Cuarto virus in maize (natural vectors: *Delphacodes kuscheli* and *Delphacodes hayward*) could be more frequent; and wheat head fusariosis will increase slightly in the south of the Pampas region by the end of the century (ECLAC, 2010a). In Brazil favorable areas for soybean and coffee rusts will move toward the south, particularly for the hottest scenario of 2080 (Alves et al., 2011). Potato late blight (*Phytophtora infestans*) severity is expected to increase in Peru (Giraldo et al., 2010).

The choice of livestock species could change in the future. For example, by 2060, under a hot and dry scenario, beef and dairy cattle, pig, and chicken production choice could decrease between 0.9 and 3.2%, while sheep election could increase by 7% mainly in the Andean countries (Seo et al., 2010). Future climate could strongly affect milk production and feed intake in dairy cattle in Brazil, where substantial modifications in areas suitable for livestock, mainly in the Pernambuco region, are expected (da Silva et al., 2009). Warming and drying conditions in Nicaragua could reduce milk production, mainly among farmers who are already seriously affected under average dry season conditions (Lentes et al., 2010).

Climate change impact on regional welfare will depend not only on changes in yield, but also in international trade. According to Hertel et al. (2010), by 2030, global cereal price could change between increases of 32% (low-productivity scenario) or decreases of 16% (optimistic yield scenario). A rise in prices could benefit net exporting countries such as Brazil, where gains from terms of trade shifts could outweigh the losses due to climate change. Despite experiencing significant negative yield shocks, some countries tend to gain from higher commodity prices. However, most poor household are food purchasers and rising commodity prices tend to have a negative effect on poverty (von Braun, 2007). According to Chapter 7, increases in prices during 2007–2009 led to rising poverty in Nicaragua.

27.3.4.2. Adaptation Practices

Genetic advances and suitable soil and technological management may induce an increase in some crops' yield despite unfavorable future climate conditions. In Argentina, genetic techniques, specific scientific knowledge, and land use planning are viewed as promising sources of adaptation (Urcola et al., 2010). Adjustments in sowing dates and fertilization rates could reduce negative impacts or increase yields in maize and wheat crops in Argentina and Chile (Magrin et al., 2009; Meza and da Silva, 2009; Travasso et al., 2009b). Furthermore, in central Chile and southern Pampas in Argentina warmer climates could allow performing two crops per season, increasing productivity per unit land (Monzon et al., 2007; Meza et al., 2008). In Brazil, adaptation strategies for coffee crops include planting at high densities, vegetated soil, accurate irrigation and breeding programs, and shading management system (arborization) (Camargo, 2010). Shading is also used in Costa Rica and Colombia. In south Brazil, a good option for irrigated rice could be to plant early cultivars (Walter et al., 2010).

Water management is another option for needed better preparedness regarding water scarcity (see Section 27.3.1). In Chile, the adoption of water conservation practices depends on social capital, farm size, and land use; and the adoption of technologies that require investment depend on the access to credit and irrigation water subsidies (Jara-Rojas et al., 2012). Deficit irrigation could be an effective measure for water savings in dry areas such as the Bolivian Altiplano (quinoa), central Brazil (tomatoes), and northern Argentina (cotton) (Geerts and Raes, 2009). In rainfed crops adaptive strategies might need to look at the harvest, storage, temporal transfer, and efficient use of rainfall water. In addition, some agronomic practices such as fallowing, crop sequences, groundwater management, no-till operations, cover crops, and fertilization could improve the adaptation to water scarcity (Quiroga and Gaggioli, 2011).

One approach to adapting to future climate change is by assisting people to cope with current climate variability (Baethgen, 2010), for which the use of climatic forecasts in agricultural planning presents a measure. Increased access and improvement of climate forecast information enhances the ability of farmers in the Brazilian Amazon to cope with El Niño impacts (Moran et al., 2006). The Southern Oscillation Index for maize and the South Atlantic Sea Surface Temperature for soybean and sunflower were the best indicators of annual crop yield variability in Argentina (Travasso et al., 2009a). Another possibility to cope with extreme events consists in transferring weather-related risks by using different types of rural insurance (Baethgen, 2010). Index insurance is one mechanism that has been recently introduced to overcome obstacles to traditional agricultural and disaster insurance markets (see Chapter 15). For the support of such parametric agricultural insurance, a Central American climate database was recently established (SICA, 2013).

Local and indigenous knowledge has the potential to bring solutions even in the face of rapidly changing climatic conditions (Folke et al., 2002; Altieri and Koohafkan, 2008), although migration, climate change, and market integration are reducing indigenous capacity for dealing with weather and climate risk (Pérez et al., 2010; Valdivia et al., 2010). Crop diversification is used in the Peruvian Andes to suppress pest outbreaks and dampen pathogen transmission (Lin, 2011). In Honduras, Nicaragua, and Guatemala traditional practices have proven more resilient to erosion and runoff and have helped retain more topsoil and moisture (Holt-Gimenez, 2002). In El Salvador, if local sustainability efforts continue, the future climate vulnerability index could only slightly increase by 2015 (Aguilar et al., 2009). Studies with Indigenous farmers in highland Bolivia and Peru indicate that constraints on access to key resources must be addressed for reducing vulnerability over time (McDowell and Hess, 2012; Sietz et al., 2012). In Guatemala and Honduras adaptive response between coffees farmers is mainly related to land availability, while participation in organized groups and access to information contribute to adaptive decision making (Tucker et al., 2010). Otherwise, adaptation may include an orientation toward non-farming activities to sustain their livelihoods and be able to meet their food requirements (Sietz, 2011). In NEB increasing vulnerability related to degradation of natural resources (due to overuse of soil and water) encouraged farmers toward off-farm activities; however, they could not improve their well-being (Sietz et al., 2006, 2011). Migration is another strategy in ecosystems and regions at high risk of climate hazards (see Section 27.3.1.1). During 1970–2000 LA and the Caribbean has had a great rate of net migration per population in the dryland zones (de Sherbinin et al., 2012). In CA nearly 25% of the surveyed households reported some type of migration during the coffee crisis (Tucker et al., 2010). Some migrations—for example, Guatemala, 1960s–1990s; El Salvador, 1950s–1980s; NEB, 1960s–present—have provoked conflict in receiving areas (Reuveny, 2007).

Shifting in agricultural zoning has been an autonomous adaptation observed in SA. In Argentina., for example, increases in precipitation promoted the expansion of the agricultural frontier to the west and north of the traditional agricultural area, resulting in environmental damage that could be aggravated in the future (República Argentina, 2007; Barros, 2008b). Adjustment of production practices—like those of farmers in the semi-arid zones of mountain regions of Bolivia, which began as they noticed strong changes in the climate since the 1980s, including upward migration of crops, selection of more resistant varieties, and water capturing—presents a further adaptation measure (PNCC, 2007).

Organic systems could enhance adaptive capacity as a result of the application of traditional skills and farmers' knowledge, soil fertility-building techniques, and a high degree of diversity (ITC, 2007). As mentioned previously, crop diversity, local knowledge, soil conservation, and economic diversity are all documented strategies for managing risk in CA and SA. A controversial but important issue in relation to adaptation is the use of genetically modified plants to produce food, with biotech crops being a strategy to cope with the needed food productivity increase considering the global population trend (see Chapter 7). Brazil and Argentina are the second and third fastest growing biotech crop producers in the world after the USA (Marshall, 2012). However, this option is problematic for the small farms (Mercer et al., 2012), which are least favorable toward GMO (Soleri et al., 2008). According to Eakin and Wehbe (2009) some practices could be an adaptive option for specific farm enterprises, but may have maladaptive implications at regional scales, and over time become maladaptive for individual enterprises.

27.3.5. Human Settlements, Industry, and Infrastructure

According to the World Bank database (World Bank, 2012) CA and SA are the geographic regions with the second highest urban population (79%), behind North America (82%) and well above the world average (50%). Therefore this section focuses on assessing the literature on climate change impacts and vulnerability of urban human settlements. The information provided should be complemented with other sections of the chapter (see Sections 27.2.2.2, 27.3.1, 27.3.3, 27.3.7).

27.3.5.1. Observed and Projected Impacts and Vulnerabilities

Urban human settlements suffer from many of the vulnerabilities and impacts already presented in several sections of this chapter. The provision of critical resources and services as already discussed in the chapter—water, health, and energy—and of adequate infrastructure and housing remain determinants of urban vulnerability that are enhanced by climate change (Smolka and Larangeira, 2008; Winchester, 2008; Roberts, 2009; Romero-Lankao et al., 2012c, 2013b).

Water resource management (see Section 27.3.1) is a major concern for many cities that need to provide both drinking water and sanitation (Henríquez Ruiz, 2009). More than 20% of the population in the region are concentrated in the largest city in each country (World Bank, 2012), hence water availability for human consumption in the region's megacities (e.g., São Paulo, Santiago, Lima, Buenos Aires) is of great concern. In this context, reduction in glacier and snowmelt related runoff in the

Box 27-2 | Vulnerability of South American Megacities to Climate Change: The Case of the Metropolitan Region of São Paulo

Research in the Metropolitan Region of São Paulo (MRSP), between 2009 and 2011, represents a comprehensive and interdisciplinary project on the impacts of climate variability and change, and vulnerability of Brazilian megacities. Studies derived from this project (Nobre et al., 2011; Marengo et al., 2013b) identify the impacts of climate extremes on the occurrence of natural disasters and human health. These impacts are linked to a projected increase of 38% in the extension of the urban area of the MRSP by 2030, accompanied by a projected increase in rainfall extremes. These may induce an intensification of urban flash floods and landslides, affecting large populated areas already vulnerable to climate extremes and variability. The urbanization process in the MRSP has been affecting the local climate, and the intensification of the heat island effect to a certain degree may be responsible for the 2°C warming detected in the city during the last 50 years (Nobre et al., 2011). This warming has been further accompanied by an increase in heavy precipitation as well as more frequent warm nights (Silva Dias et al., 2012; Marengo et al., 2013b). By 2100, climate projections based on data from 1933–2010 show an expected warming between 2°C and 3°C in the MRSP, together with a possible doubling of the number of days with heavy precipitation in comparison to the present (Silva Dias et al., 2012; Marengo et al., 2013b).

With the projected changes in climate and in the extension of the MRSP (Marengo et al., 2013b) more than 20% of the total area of the city could be potentially affected by natural disasters. More frequent floods may increase the risk of leptospirosis, which, together with increasing air pollution and worsening environmental conditions that trigger the risk of respiratory diseases, would leave the population of the MRSP more vulnerable. Potential adaptation measures include a set of strategies that need to be developed by the MRSP and its institutions to face these environmental changes. These include improved building controls to avoid construction in risk areas, investment in public transportation, protection of the urban basins, and the creation of forest corridors in the collecting basins and slope regions. The lessons learned suggest that the knowledge on the observed and projected environmental changes, as well as on the vulnerability of populations living in risk areas, is of great importance for defining adaptation policies that in turn constitute a first step toward building resilient cities that in turn improve urban quality of life in Brazil.

Andes poses important adaptation challenges for many cities, for example, the metropolitan areas of Lima, La Paz/El Alto, and Santiago de Chile (Bradley et al., 2006; Hegglin and Huggel, 2008; Melo et al., 2010). Flooding is also a preoccupation in several cities. In São Paulo for example, according to Marengo et al. (2009b, 2013b) the number of days with rainfall above 50 mm were almost zero during the 1950s and now they occur between two and five times per year (2000–2010). The increase in precipitation is one of the expected risks affecting the city of São Paulo as presented in Box 27-2. Increases in flood events during 1980–2000 have been observed also in the Buenos Aires province and Metropolitan Area (Andrade and Scarpati, 2007; Barros et al., 2008; Hegglin and Huggel, 2008; Nabel et al., 2008). There are also the combined effects of climate change impacts, human settlements' features, and other stresses, such as more intense pollution events (Moreno, 2006; Nobre, 2011; Nobre et al., 2011; Romero-Lankao et al., 2013b) and more intense hydrological cycles from urban heat island effects. In terms of these combined effects, peri-urban areas and irregular settlements pose particular challenges to urban governance and risk management given their scale, lack of infrastructure, and socioeconomic fragility (Romero-Lankao et al., 2012a).

Changes in prevailing urban climates have led to changing patterns of disease vectors, and water-borne disease issues linked to water availability and subsequent quality (see Section 27.3.7). The influence of climate change on particulate matter and other local contaminants is another concern (Moreno, 2006; Romero-Lankao et al., 2013b). It is important to highlight the relationship between water and health, given the problems of water stress and intense precipitation events affecting many urban centers. Both relate to changing disease risks, as well as wider problems of event-related mortalities and morbidity, and infrastructure and property damage. These risks are compounded for low-income groups in settlements with little or no service provision, for example, waste collection, piped drinking water, and sanitation (ECLAC, 2008). Existing cases of flooding, air pollution, and heat waves reveal that not only low-income groups are at risk, but also that wealthier sectors are not spared. Factors such as high-density settlement (Barros et al., 2008) and the characteristics of some hazards explain this—for example, poor and wealthy alike are at risk from air pollution and temperature in Santiago de Chile and Bogotá (Romero-Lankao et al., 2012b, 2013b).

There are also other climate change risks in terms of economic activity location and impacts on urban manufacturing and service workers (e.g., thermal stress; Hsiang, 2010) and the forms of urban expansion or sprawl into areas where ecosystem services may be compromised and risks enhanced (e.g., floodplains). Both processes are also related to rising motorization rates that facilitate suburban development and new regional agglomerations that bring pressure to bear on land uses that favor infiltration, surface cooling, and biodiversity; the number of light vehicles in LA and the Caribbean is expected to double between 2000 and 2030, and be three times the 2000 figure by 2050 (Samaniego, 2009).

While urban populations face diverse social, political, economic, and environmental risks in daily life, climate change adds a new dimension to these risk settings (Pielke, Jr. et al., 2003; Roberts, 2009; Romero-Lankao and Qin, 2011). Because urban development remains fragile in many cases, with weak planning responses, climate change can compound existing challenges. The probabilities and magnitudes of these events in each urban center will differ significantly according to socioeconomic, institutional, and physical contexts.

27.3.5.2. Adaptation Practices

The direct and indirect effects of climate change such as flooding, heat islands, and food insecurity present cities with a set of challenges and opportunities for mainstreaming flood management, warning systems, and other adaptation responses with sustainability goals (Bradley et al., 2006; Hegglin and Huggel, 2008; Hardoy and Pandiella, 2009; Romero-Lankao, 2010, 2012a; Romero-Lankao et al., 2013a).

Urban populations, economic activities, and authorities have a long experience of responding to climate-related hazards, particularly through disaster risk management, for example, Tucuman and San Martin, Argentina (Plaza and Pasculi, 2007; Sayago et al., 2010), and land use and economic development planning to a limited extent (Barton, 2009). Climate policies can build on these. Local administrations participate in the International Council for Local Environmental Initiatives (ICLEI), Cities Climate Leadership Group (C40), Inter-American Development Bank (IDB), Emerging and Sustainable Cities Initiative (ESCI) (IDB, 2013), and other networks, demonstrating their engagement in the generation of more climate-resilient cities. In smaller settlements, there is less capacity for adequate responses, for example, climate change and vulnerability information (Hardoy and Romero-Lankao, 2011). Policies, plans, and programs are required to reduce social vulnerability, and identify and reduce potential economic effects of climate on the local economy. Rio de Janeiro, for example, with its coastline property and high dependence on tourists (and their perceptions of risk), cannot ignore these climate-related hazards (Gasper et al., 2011).

Poverty and vulnerability, as interlinked elements of the adaptation challenge in CA and SA, remain pivotal to understanding how urban climate policies can be streamlined with broader development issues and not solely the capacity to respond to climate change (Hardoy and Pandiella, 2009; Winchester and Szalachman, 2009; Hardoy and Romero-Lankao, 2011). These broader links include addressing the determinants of vulnerability (e.g., access to education, health care, and infrastructure, and to emergency response systems (Romero-Lankao, 2007a; Romero-Lankao and Qin, 2011)). Among these response options, a focus on social assets has been highlighted by Rubin and Rossing (2012), rather than a purely physical asset focus.

Much urbanization involves in-migrating or already resident, low-income groups and their location in risk-prone zones (da Costa Fereira et al., 2011). The need to consider land use arrangements, particularly urban growth on risk-prone zones, as part of climate change adaptation highlights the role of green areas that mitigate the heat island effect and reduce risks from landslides and flooding (Rodríguez Laredo, 2011; Krellenberg et al., 2013).

In the case of governance frameworks, there is clear evidence that incorporation of climate change considerations into wider city planning is still a challenge, as are more inter-sectoral and participative processes that have been linked to more effective policies (Barton, 2009, 2013; de Oliveira, 2009; Romero-Lankao et al., 2013a). Several metropolitan adaptation plans have been generated over the last 5 years, for example, Bogotá, Buenos Aires, Esmeraldas, Quito, and São Paulo, although for the most part they have been restricted to the largest conglomerations and are often included as an addition to mitigation plans (Romero-Lankao, 2007b; Carmin et al., 2009; Romero-Lankao et al., 2012b, 2013a; Luque et al., 2013).

27.3.6. Renewable Energy

27.3.6.1. Observed and Projected Impacts and Vulnerabilities

Table 27-6 shows the relevance of renewable energy in the LA energy matrix as compared to the world for 2009 according to IEA statistics (IEA, 2012). Hydropower is the most representative source of renewable energy and therefore analyzed separately (see the case study in Section 27.6.1.). Geothermal energy is not discussed, as it is assumed that there is no impact of climate change on the effectiveness of this energy type (Arvizu et al., 2011).

Hydro, wind energy, and biofuel production might be sensitive to climate change in Brazil (de Lucena et al., 2009). With the vital role that renewable energy plays in mitigating the effects of climate change, being by far the most important sources of non-hydro renewable energy in SA and CA, this sensitivity demands the implementation of renewable energy projects that will increase knowledge on the crops providing bioenergy.

For historical reasons, CA and SA developed sugarcane as bioenergy feedstock. Brazil accounts for the most intensive renewable energy production as bioethanol, which is used by the majority of the cars in the country (Goldemberg, 2008) whereas biodiesel comprises 5% of all diesel nationwide. With the continent's long latitudinal length, the expected impacts of climate change on plants will be complex owing to a wide variety of climate conditions, so that different crops would have to be used in different regions. In Brazil, most of the biodiesel comes from soybeans, but there are promising new sources such as palm oil (de Lucena et al., 2009). The development of palm oil as well as soybean are important factors that induce land use change, with a potential to influence stability of forests and biodiversity in certain key regions in SA, such as the Amazon (Section 27.2.2.1).

Biofuels can help CA and SA to decrease emissions from energy production and use. However, renewable energy might imply potential problems such as those related to positive net emissions of GHGs, threats to biodiversity, an increase in food prices, and competition for

Table 27-6 | Comparison of consumption of different energy sources in Latin America and the world (in thousand tonnes of oil equivalent on a net calorific value basis).

Energy resource		Latin America						World					
		TFC (non-electricity)		TFC (via electricity generation)		TFC (total)		TFC (non-electricity)		TFC (via electricity generation)		TFC (total)	
Fossil	Coal and peat	9008	3%	1398	2%	10,406	3%	831,897	12%	581,248	40%	1,413,145	17%
	Oil	189,313	55%	8685	13%	197,998	48%	3,462,133	52%	73,552	5%	3,535,685	44%
	Natural gas	59,440	17%	9423	14%	68,863	17%	1,265,862	19%	307,956	21%	1,573,818	19%
Nuclear		0	0%	1449	2%	1449	0%	0	0%	193,075	13%	193,075	2%
Renewable	Biofuels and waste	82,997	24%	2179	3%	85,176	21%	1,080,039	16%	20,630	1%	1,100,669	14%
	Hydropower	0	0%	45,920	66%	45,920	11%	0	0%	238,313	17%	238,313	3%
	Geothermal, solar, wind, other renewable	408	0%	364	1%	772	0%	18,265	0%	26,592	2%	44,857	1%
Total		341,166	100%	69,418	100%	410,584	100%	6,658,196	100%	1,441,366	100%	8,099,562	100%

TFC = Total final consumption.

Source: IEA (2012).

water resources (Section 27.2.3), some of which can be reverted or attenuated (Koh and Ghazoul, 2008). For example, the sugarcane agro-industry in Brazil combusts bagasse to produce electricity, providing power for the bioethanol industry and increasing sustainability. The excess heat energy is then used to generate bioelectricity, thus allowing the biorefinery to be self-sufficient in energy utilization (Amorim et al., 2011; Dias et al., 2012). In 2005–2006 the production of bioelectricity was estimated to be 9.2 kWh per tonne of sugarcane (Macedo et al., 2008). Most bioenergy feedstocks at present in production in CA and SA are grasses. In the case of sugarcane, the responses to the elevation of CO_2 concentration up to 720 ppmv have been shown to be positive in terms of biomass production and principally regarding water use efficiency (de Souza et al., 2008).

The production of energy from renewable sources such as hydro- and wind power is greatly dependent on climatic conditions and therefore may be impacted in the future by climate change. de Lucena et al. (2010a) suggest an increasing energy vulnerability of the poorest regions of Brazil to climate change together with a possible negative influence on biofuels production and electricity generation, mainly biodiesel and hydropower respectively.

Expansion of biofuel crops in Brazil might cause both direct and indirect land use changes (e.g., biofuel crops replacing rangelands, which previously replaced forests) with the direct land use changes, according to simulation performed by Lapola et al. (2010) of the effects for 2020. The same study shows that sugarcane ethanol and biodiesel derived from soybean each contribute, with about one-half of the indirect deforestation projected for 2020 (121,970 km²) (Lapola et al., 2010). Thus, indirect land use changes, especially those causing the rangeland frontier to move further into the Amazonian forests, might potentially offset carbon savings from biofuel production.

The increase in global ethanol demand is leading to the development of new hydrolytic processes capable of converting cellulose into ethanol (dos Santos et al., 2011). The expected increase in the hydrolysis technologies is *very likely* to balance the requirement of land for biomass crops. Thus, the development of these technologies has a strong potential to diminish social (e.g., negative health effects due the burning process, poor labor conditions) and environmental impacts (e.g., loss of biodiversity, water and land uses) whereas it can improve the economic potential of sugarcane. One adaptation measure will be to increase the productivity of bioenergy crops due to planting in high productivity environments with highly developed technologies, in order to use less land. As one of the main centers of biotech agriculture application in the world (Gruskin, 2012), the region has a great potential to achieve this goal.

As the effects previously reported on crops growing in SESA might prevail (see Section 27.3.4.1), that is, that an increase in productivity may happen due to increasing precipitation, future uncertainty will have to be dealt with by preparing adapted varieties of soybean in order to maintain food and biodiesel production, mainly in Argentina, as it is one of the main producers of biodiesel from soybean in the world (Chum et al., 2011).

Other renewable energy sources—such as wind power generation—may also be vulnerable, raising the need for further research. According to de Lucena et al. (2009, 2010b), the projections of changes in wind power in Brazil may favor the use of this kind of energy in the future.

27.3.6.2. Adaptation Practices

Renewable energy will become increasingly more important over time, as this is closely related to the emissions of GHGs (Fischedick et al., 2011). Thus, renewable energy could have an important role as adaptation means to provide sustainable energy for development in the region (see also Section 27.6.1). However, the production of renewable energy requires large available areas for agriculture, which is the case of

Argentina, Bolivia, Brazil, Chile, Colombia, Peru, and Venezuela, which together represent 90% of the total area of CA and SA. However, for small countries it might not be possible to use bioenergy. Instead, they could benefit in the future from other types of renewable energy, such as geothermal, eolic, photovoltaic, and so forth, depending on policies and investment in different technologies. This is important because economic development is thought to be strongly correlated with an increase in energy use (Smil, 2000), which is itself associated with an increase in emissions (Sathaye et al., 2011).

LA is second to Africa in terms of technical potential for bioenergy production from rainfed lignocellulosic feedstocks on unprotected grassland and woodlands (Chum et al., 2011). Among the most important adaptation measures regarding renewable energy are (1) management of land use change ; and (2) development of policies for financing and management of science and technology for all types of renewable energy in the region.

If carefully managed, biofuel crops can be used as a means to regenerate biodiversity as proposed by Buckeridge et al. (2012), highlighting that the technology for tropical forest regeneration has become available and that forests could share land with biofuel crops (such as sugarcane) taking advantage of forests' mitigating potential. A possible adaptation measure could be to expand the use of reforestation technology to other countries in CA and SA.

One of the main adaptation issues is related to food versus fuel (Valentine et al., 2012). This is important because an increase in bioenergy feedstocks might threaten primary food production in a scenario expected to feed future populations with an increase of 70% in production (Gruskin, 2012; Valentine et al., 2012). This is particularly important in the region, as it has one of the highest percentages of arable land available for food production in the world (Nellemann et al., 2009). As CA and SA develop new strategies to produce more renewable energy there might be a pressure for more acreage to produce bioenergy. Because climate change will affect bioenergy and food crops at the same time, their effects, as well as the adaptation measures related to agriculture, will be similar. The main risks identified by Arvizu et al. (2011) are (1) business as usual, (2) unreconciled growth, and (3) environment and food versus fuel. Thus, the most important adaptation measures will be the ones related to the control of economic growth, environmental management, and agriculture production. The choice for lignocellulosic feedstocks (e.g., sugarcane second-generation technologies) will be an important mitigation/adaptation measure because these feedstocks do not compete with food (Arvizu et al., 2011). In the case of sugarcane, for instance, an increase of approximately 40% in the production of bioethanol is expected as a result of the implantation of second-generation technologies coupled with the first-generation ones already existent in Brazil (Dias et al., 2012; de Souza et al., 2013).

Biodiesel production has the lowest costs in LA (Chum et al., 2011) owing to the high production of soybean in Brazil and Argentina. The use of biodiesel to complement oil-derived diesel is a productive choice for adaptation measures regarding this bioenergy source. Also, the cost of ethanol, mainly derived from sugarcane, is the lowest in CA, SA, and LA (Chum et al., 2011) and as an adaptation measure, such costs, as well as the one of biodiesel, should be lowered even more by improving technologies related to agricultural and industrial production of both. Indeed, it has been reported that in LA the use of agricultural budgets by governments for investment in public goods induces faster growth, decreasing poverty and environmental degradation (López and Galinato, 2007). The pressure of soy expansion due to biodiesel demand can lead to land use change and consequently to economic teleconnections, as suggested by Nepstad et al. (2006). These teleconnections may link Amazon deforestation derived from soy expansion to economic growth in some developing countries because of changes in the demand of soy. These effects may possibly mean a decrease in jobs related to small to big farms in agriculture in Argentina (Tomei and Upham, 2009) on the one hand, and deforestation in the Amazon due to the advance of soybean cropping in the region on the other (Nepstad and Stickler, 2008).

27.3.7. Human Health

27.3.7.1. Observed and Projected Impacts and Vulnerabilities

Changes in weather extremes and climatic patterns are affecting human health (*high confidence*), by increasing morbidity, mortality, and disabilities, and through the emergence of diseases in previously non-endemic regions (*high confidence*; Winchester and Szalachman, 2009; Rodríguez-Morales, 2011). Heat waves and cold spells have increased urban mortality rates (McMichael et al., 2006; Bell et al., 2008; Hardoy and Pandiella, 2009; Muggeo and Hajat, 2009; Hajat et al., 2010). Outbreaks of vector- and water-borne diseases were triggered in CA by Hurricane Mitch in 1998 (Costello et al., 2009; Rodríguez-Morales et al., 2010), while the 2010–2012 Colombian floods caused hundreds of deaths and displaced thousands of people (Hoyos et al., 2012).

The number of cases of malaria have increased in Colombia during the last 5 decades alongside air temperatures (Poveda et al., 2011; Arevalo-Herrera et al., 2012), but also in urban and rural Amazonian regions undergoing large environmental changes (Gil et al., 2007; Tada et al., 2007; Cabral et al., 2010; da Silva-Nunes et al., 2012). Malaria transmission has reached 2300 m in the Bolivian Andes, and vectors are found at higher altitudes from Venezuela to Bolivia (Benítez and Rodríguez-Morales, 2004; Lardeux et al., 2007; Pinault and Hunter, 2011).

Although the incidence of malaria has decreased in Argentina, its vector density has increased in the northwest along with climate variables (Dantur Juri et al., 2010, 2011). El Niño drives malaria outbreaks in Colombia (Mantilla et al., 2009; Poveda et al., 2011), amidst other factors (Rodríguez-Morales et al., 2006; Osorio et al., 2007; Restrepo-Pineda et al., 2008). Linkages between ENSO and malaria are also reported in Ecuador and Peru (Anyamba et al., 2006; Kelly-Hope and Thomson, 2010), French Guiana (Hanf et al., 2011), Amazonia (Olson et al., 2009), and Venezuela (Moreno et al., 2007).

Unlike malaria, dengue fever and its hemorrhagic variant are mostly urban diseases whose vector is affected by climate conditions. Their incidence have risen in tropical America in the last 25 years, causing annual economic losses of US$2.1+ (1 to 4) billion (Torres and Castro, 2007; Tapia-Conyer et al., 2009; Shepard et al., 2011). Environmental and climatic variability affect their incidence in CA (Fuller et al., 2009; Rodríguez-Morales et al., 2010; Mena et al., 2011), in Colombia

(Arboleda et al., 2009), and in French Guiana alongside malaria (Carme et al., 2009; Gharbi et al., 2011). In Venezuela, dengue fever increases during La Niña (Rodríguez-Morales and Herrera-Martinez, 2009; Herrera-Martinez and Rodríguez-Morales, 2010). Weather and climate variability are also associated with dengue fever in southern SA (Honório et al., 2009; Costa et al., 2010; de Carvalho-Leandro et al., 2010; Degallier et al., 2010; Lowe et al., 2011), involving also demographic and geographic factors in Argentina (Carbajo et al., 2012). In Rio de Janeiro a 1°C increase in monthly minimum temperature led to a 45% increase of dengue fever in the next month, and 10 mm increase in rainfall to a 6% increase (Gomes et al., 2012). Despite large vaccination campaigns, the risk of yellow fever outbreaks has increased mostly in tropical America's densely populated poor urban settings (Gardner and Ryman, 2010), alongside climate conditions (Jentes et al., 2011).

Schistosomiasis is endemic in rural areas of Suriname, Venezuela, the Andean highlands, and rural and peripheral urbanized regions of Brazil (Barbosa et al., 2010; Kelly-Hope and Thomson, 2010; Igreja, 2011). It is *highly likely* that schistosomiasis will increase in a warmer climate (Mangal et al., 2008; Mas-Coma et al., 2009; Lopes et al., 2010). Vegetation indices are associated with human fascioliasis in the Andes (Fuentes, 2004).

Hantaviruses have been recently reported throughout the region (Jonsson et al., 2010; MacNeil et al., 2011), and El Niño and climate change augment their prevalence (Dearing and Dizney, 2010). Variation in hantavirus reservoirs in Patagonia is strongly dependent on climate and environmental conditions (Andreo et al., 2012; Carbajo et al., 2009). In Venezuela, rotavirus is more frequent and more severe in cities with minimal seasonality (Kane et al., 2004). The peak of rotavirus in Guatemala occurs in the dry season, causing 60% of total diarrhea cases (Cortes et al., 2012).

In spite of its rapid decline, climate-sensitive Chagas disease is still a major public health issue (Tourre et al., 2008; Moncayo and Silveira, 2009; Abad-Franch et al., 2009; Araújo et al., 2009; Gottdenker et al., 2011). Climate also affects the most prevalent mycosis (Barrozo et al., 2009), and ENSO is associated with outbreaks of bartonellosis in Peru (Payne and Fitchett, 2010).

The high incidence of cutaneous leishmaniasis in Bolivia is exacerbated during La Niña (Gomez et al., 2006; García et al., 2009). Cutaneous leishmaniasis is affected in Costa Rica by temperature, forest cover, and ENSO (Chaves et al., 2008), and in Colombia by land cover, altitude, climatic variables, and El Niño (Cárdenas et al., 2006, 2007, 2008; Valderrama-Ardila et al., 2010), and decreases during La Niña in Venezuela (Cabaniel et al., 2005). Cutaneous leishmaniasis in Suriname peaks during the March dry season (35%; van der Meide et al., 2008), and in French Guiana is intensified after the October-December dry season (Rotureau et al., 2007). The incidence of visceral leishmaniasis has increased in Brazil (highest in LA) in association with El Niño and deforestation (Ready, 2008; Cascio et al., 2011; Sortino-Rachou et al., 2011), as in Argentina, Paraguay, and Uruguay (Bern et al., 2008; Dupnik et al., 2011; Salomón et al., 2011; Fernández et al., 2012). Visceral leishmaniasis transmission in Venezuela is associated with rainfall seasonality (Feliciangeli et al., 2006; Rodríguez-Morales et al., 2007). The incidence of skin cancer in Chile has increased in recent years, concomitantly with climate and geographic variables (Salinas et al., 2006).

Onchocerciasis (river blindness) vector exhibits seasonal biting rates (Botto et al., 2005; Rodríguez-Pérez et al., 2011), and leptospirosis is prevalent in CA's warm-humid tropical regions (Valverde et al., 2008). Other climate-driven infectious diseases are ascariasis and gram-positive cocci in Venezuela (Benítez et al., 2004; Rodríguez-Morales et al., 2010) and Carrion's disease in Peru (Huarcaya et al., 2004).

Seawater temperature affects the abundance of cholera bacteria (Koelle, 2009; Jutla et al., 2010; Marcheggiani et al., 2010; Hofstra, 2011), which explains the outbreaks during El Niño in Peru, Ecuador, Colombia, and Venezuela (Cerda Lorca et al., 2008; Martínez-Urtaza et al., 2008; Salazar-Lindo et al., 2008; Holmner et al., 2010; Gavilán and Martínez-Urtaza, 2011; Murugaiah, 2011).

The worsening of air quality and higher temperatures in urban settings are increasing chronic respiratory and cardiovascular diseases, and morbidity from asthma and rhinitis (Grass and Cane, 2008; Martins and Andrade, 2008; Gurjar et al., 2010; Jasinski et al., 2011; Rodriguez et al., 2011), but also atherosclerosis, pregnancy-related outcomes, cancer, cognitive deficit, otitis, and diabetes (Olmo et al., 2011). Dehydration

Frequently Asked Questions

FAQ 27.3 | Are there emerging and reemerging human diseases as a consequence of climate variability and change in the region?

Human health impacts have been exacerbated by variations and changes in climate extremes. Climate-related diseases have appeared in previously non-endemic regions (e.g., malaria in the Andes, dengue in CA and southern SA) (*high confidence*). Climate variability and air pollution have also contributed to increase the incidence of respiratory and cardiovascular, vector- and water-borne and chronic kidney diseases, hantaviruses and rotaviruses, pregnancy-related outcomes, and psychological trauma (*very high confidence*). Health vulnerabilities vary with geography, age, gender, ethnicity, and socioeconomic status, and are rising in large cities. Without adaptation measures (e.g., extending basic public health services), climate change will exacerbate future health risks, owing to population growth rates and existing vulnerabilities in health, water, sanitation and waste collection systems, nutrition, pollution, and food production in poor regions (*medium confidence*).

from heat waves increases hospitalizations for chronic kidney diseases (Kjellstrom et al., 2010), affecting construction, sugarcane, and cotton workers in CA (Crowe et al., 2009, 2010; Kjellstrom and Crowe, 2011; Peraza et al., 2012).

Extreme weather/climate events affect mental health in Brazil (depression, psychological distress, anxiety, mania, and bipolar disorder), in particular in drought-prone areas of NEB (Coêlho et al., 2004; Volpe et al., 2010). Extreme weather, meager crop yields, and low GDP are also associated with increased violence (McMichael et al., 2006).

Multiple factors increase the region's vulnerability to climate change: precarious health systems; malnutrition; inadequate water and sanitation services; poor waste collection and treatment systems; air, soil, and water pollution; lack of social participation; and inadequate governance (Luber and Prudent, 2009; Rodríguez-Morales, 2011; Sverdlik, 2011). Human health vulnerabilities in the region depend on geography, age (Perera, 2008; Martiello and Giacchi, 2010; Åstrom et al., 2011; Graham et al., 2011), gender (de Oliveira et al., 2011), race, ethnicity, and socioeconomic status (Diez Roux et al., 2007; Martiello and Giacchi, 2010). Neglected tropical diseases in LA cause 1.5 to 5.0 million disability-adjusted life years (DALYs) (Hotez et al., 2008).

Vulnerability of megacities (see Section 27.3.5) is aggravated by access to clean water, rapid spread of diseases (Borsdorf and Coy, 2009), and migration from rural areas forced by disasters (Campbell-Lendrum and Corvalán, 2007; Borsdorf and Coy, 2009; Hardoy and Pandiella, 2009). Human health vulnerabilities have been assessed in Brazil through composite indicators involving epidemiological variables, downscaled climate scenarios, and socioeconomic projections (Confalonieri et al., 2009; Barata et al., 2011; Barbieri and Confalonieri, 2011). The Andes and CA are among the regions of highest predicted losses (1 to 27%) in labor productivity from future climate scenarios (Kjellstrom et al., 2009).

27.3.7.2. Adaptation Strategies and Practices

Adaptation efforts in the region (Blashki et al., 2007; Costello et al., 2011) are hampered by lack of political commitment, gaps in scientific knowledge, and institutional weaknesses (Keim, 2008; Lesnikowski et al., 2011; Olmo et al., 2011; see Section 27.4.3). Research priorities and current strategies must be reviewed (Halsnæs and Verhagen, 2007; Romero and Boelaert, 2010; Karanja et al., 2011), and preventive/responsive systems must be put in place (Bell, 2011) to foster adaptive capacity (Campbell-Lendrum and Bertollini, 2010; Huang et al., 2011). Colombia established a pilot adaptation program to cope with changes in malaria transmission and exposure (Poveda et al., 2011). The city of São Paulo has implemented local pollution control measures, with the co-benefit of reducing GHG emissions (de Oliveira, 2009; Nath and Behera, 2011).

Human well-being indices must be explicitly stated as adaptation policies in LA (e.g., Millennium Development Goals; Franco-Paredes et al., 2007; Halsnæs and Verhagen, 2007; Mitra and Rodriguez-Fernandez, 2010). South–south cooperation and multidisciplinary research are required to design relevant adaptation and mitigation strategies (Tirado et al., 2010; Team and Manderson, 2011).

27.4. Adaptation Opportunities, Constraints, and Limits

27.4.1. Adaptation Needs and Gaps

During the last few years, the study of adaptation to climate change has progressively switched from an impact-focused approach (mainly climate-driven) to include a vulnerability-focused vision (Boulanger et al., 2011). As a consequence, the development and implementation of systemic adaptation strategies, involving institutional, social, ecosystem, environmental, financial, and capacity components (see Chapter 14) to cope with present climate extreme events is a key step toward climate change adaptation, especially in SA and CA countries. Although different frameworks and definitions of vulnerability exist, a general tendency aims at studying vulnerability to climate change, especially in SA and CA, focusing on the following aspects: urban vulnerability (e.g., Hardoy and Pandiella, 2009; Heinrichs and Krellenberg, 2011), rural community (McSweeney and Coomes, 2011; Ravera et al., 2011), rural farmer vulnerability (Oft, 2010), and sectoral vulnerability (see Section 27.3). The approach used can be holistic or systemic (Ison, 2010; Carey et al., 2012b), where climate drivers are actually few with respect to all other drivers related to human and environment interactions including physical, economic, political, and social context, as well as local characteristics such as occupations, resource uses, accessibility to water, and so forth (Manuel-Navarrete et al., 2007; Young et al., 2010).

In developing and emergent countries, there exists a general consensus that the adaptive capacity is low, strengthened by the fact that poverty is the key determinant of vulnerability in LA (to climate-related natural hazards; see Rubin and Rossing, 2012) and thus a limit to resilience (Pettengell, 2010) leading to a "low human development trap" (UNDP, 2007). However, Magnan (2009, p. 1) suggests that this analysis is biased by a "relative immaturity of the science of adaptation to explain what are the processes and the determinants of adaptive capacity." Increasing research efforts on the study of adaptation is therefore of great importance to improve understanding of the actual societal, economical, community, and individual drivers defining the adaptive capacity. Especially, a major focus on traditions and their transmission (Young and Lipton, 2006) may actually indicate potential adaption potentials in remote and economically poor regions of SA and CA. Such a potential does not dismiss the fact that the nature of future challenges may actually not be compared to past climate variability (e.g., glacier retreat in the Andes).

Coping with new situations may require new approaches such as a multi-level risk governance (Corfee-Morlot et al., 2011; Young and Lipton, 2006) associated with decentralization in decision making and responsibility. Although the multi-level risk governance and the local participatory approach are interesting frameworks for strengthening adaptation capacity, perception of local and national needs is diverging, challenging the implementation of adaptation strategies in CA/SA (Salzmann et al., 2009). At present, despite an important improvement during the last few years, there still exists a certain lack of awareness of environmental changes and their implications for livelihoods and businesses (Young et al., 2010). Moreover, considering the limited financial resources of some states in CA and SA, long-term planning and the related human and financial resource needs may be seen as conflicting with present social deficit in the welfare of the population. This situation weakens the importance of adaptation planning to climate change in the political agenda (Carey et al., 2012b), and therefore requires international involvement as one facilitating factor in natural hazard management and climate change adaptation, with respect to sovereignty according to international conventions including the United Nations Framework Convention on Climate Change (UNFCCC). In addition, as pointed out by McGray et al. (2007), development, adaptation, and mitigation are not separate issues. Development and adaptation strategies especially should be tackled together in developing countries such as SA and CA, focusing on strategies to reduce vulnerability. The poor level of adaptation of present-day climate in SA and CA countries is characterized by the fact that responses to disasters are mainly reactive rather than preventive. Some early warning systems are being implemented, but the capacity of responding to a warning is often limited, particularly among poor populations. Finally, actions combining public communication (and education), public decision-maker capacity-building, and a synergetic development-adaptation funding will be key to sustain the adaptation process that CA and SA require to face future climate change challenges.

27.4.2. Practical Experiences of Autonomous and Planned Adaptation, Including Lessons Learned

Adaptation processes in many cases have been initiated a few years ago, and there is still a lack of literature to evaluate their efficiency in reducing vulnerability and building resilience of the society against climate change. However, experiences of effective adaptation and maladaptation are slowly being documented (see also Section 27.4.3); some lessons have already been learned from these first experiences (see Section 27.3); and tools, such as the Index of Usefulness of Practices for Adaptation (IUPA) to evaluate adaptation practices, have been developed for the region (Debels et al., 2009). Evidenced by these practical experiences, there is a wide range of options to foster adaptation and thus adaptive capacity in CA and SA. In CA and SA, many societal issues are strongly connected to development goals and are often considered a priority in comparison to adaptation efforts to climate change. However, according to the 135 case studies analyzed by McGray et al. (2007), 21 of which were in CA and SA, the synergy between development and adaptation actions makes it possible to ensure a sustainable result of the development projects.

Vulnerability and disaster risk reduction may not always lead to long-term adaptive capacity (Tompkins et al., 2008; Nelson and Finan, 2009), except when structural reforms based on good governance (Tompkins et al., 2008) and negotiations (de Souza Filho and Brown, 2009) are implemented. While multi-level governance can help to create resilience and reduce vulnerability (Roncoli, 2006; Young and Lipton, 2006; Corfee-Morlot et al., 2011), capacity-building (Eakin and Lemos, 2006), good governance, and enforcement (Lemos et al., 2010; Pittock, 2011) are key components.

Autonomous adaptation experience is mainly realized at local levels (individual or communitarian) with examples found, for instance, for rural communities in Honduras (McSweeney and Coomes, 2011), Indigenous communities in Bolivia (Valdivia et al., 2010), and coffee agroforestry systems in Brazil (de Souza et al., 2012). However, such adaptation processes do not always respond specifically to climate forcing. For instance, the agricultural sector adapts rapidly to economic stressors, although, despite a clear perception of climate risks, it may last longer before responding to climate changes (Tucker et al., 2010). In certain regions or communities, such as Anchioreta in Brazil (Schlindwein et al., 2011), adaptation is part of a permanent process and is actually tackled through a clear objective of vulnerability reduction, maintaining and diversifying a large set of natural varieties of corn, allowing the farmers to diversify their planting. Another kind of autonomous adaptation is the southward displacement of agriculture activities (e.g., wine, coffee) through the purchase of lands, which will become favorable for such agriculture activities in a warmer climate. In Argentina, the increase of precipitation observed during the last 30 years contributed to a westward displacement of the annual crop frontier.

However, local adaptation to climate and non-climate drivers may undermine long-term resilience of socio-ecological systems when local, short-term strategies designed to deal with specific threats or challenges do not integrate a more holistic and long-term vision of the system at threat (Adger et al., 2011). Thus, policy should identify the sources of and conditions for local resilience and strengthen their capacities to adapt and learn (Borsdorf and Coy, 2009; Adger et al., 2011; Eakin et al., 2011), as well as to integrate new adapted tools (Oft, 2010). This sets the question of convergence between the local-scale/short-term and broad-scale/long-term visions in terms of perceptions of risks, needs to adapt, and appropriate policies to be implemented (Eakin and Wehbe, 2009; Salzmann et al., 2009). Even if funding for adaptation is available, the overarching problem is the lack of capacity and/or willingness to address the risks, especially those threatening lower income groups (Satterthwaite, 2011a). Adaptation to climate change cannot eliminate the extreme weather risks, and thus efforts should focus on disaster preparedness and post-disaster response (Sverdlik, 2011). Migration is the last resort for rural communities facing water stress problems in CA and SA (Acosta-Michlik et al., 2008).

In natural hazard management contributing to climate change adaptation, specific cases such as the one in Lake 513 in Peru (Carey et al., 2012b) clearly allowed identification of facilitating factors for a successful adaptation process (technical capacity, disaster events with visible hazards, institutional support, committed individuals, and international involvement) as well as impediments (divergent risk perceptions, imposed government policies, institutional instability, knowledge disparities, and invisible hazards). In certain cases, forward-looking learning (anticipatory process), as a contrast to learning by shock (reactive process), has been found as a key element for adaptation and resilience (Tschakert and Dietrich, 2010) and should be promoted as a tool for capacity-building at all levels (stakeholders, local and national governments). Its combination with role-playing game and agent-based models (Rebaudo et al., 2011) can strengthen and accelerate the learning process.

Planned adaptation policies promoted by governments have been strengthened by participation in international networks, where experience and knowledge can be exchanged. As an example, the C40 Cities-Climate Leadership Group or ICLEI include Bogotá (Colombia), Buenos Aires (Argentina), Caracas (Venezuela), Curitiba, Rio de Janeiro, and São Paulo (Brazil), Lima (Peru), and Santiago de Chile (Chile). Most of these cities have come up with related action and strategy plans (e.g., Action Plan

Buenos Aires 2030, Plan of Caracas 2020, or the Metropolitan Strategy to CCA of Lima) (C40 Cities, 2011).

At a regional policy level, an example of intergovernmental initiatives in SA and CA is the Ibero-American Programme on Adaptation to Climate Change (PIACC), developed by the Ibero-American Network of Climate Change Offices (RIOCC) (Keller et al., 2011b). For CA specifically, the Central American Commission for Environment and Development (CCAD) brings together the environmental ministries of the Central American Integration System (Sistema de la Integración Centroamericana (SICA)) that released its climate change strategy in 2010 (CCAD and SICA, 2010; Keller et al., 2011a).

These initiatives demonstrate that there has been a growing awareness of CA and SA governments on the need to integrate climate change and future climate risks in their policies. To date, in total, 18 regional Non-Annex countries, including Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Guyana, Panama, Paraguay, Peru, Suriname, Uruguay, and Venezuela, have already published their first and/or second National Communication to the UNFCCC (see UNFCCC, 2012), making it possible to measure the country's emissions and to assess its present and future vulnerability.

27.4.3. Observed and Expected Barriers to Adaptation

Adaptation is a dynamic process, which to be efficient requires a permanent evolution and even transformation of the vulnerable system. Such a transformation process can be affected by several constraints, including constraints affecting the context of adaptation as well as the implementation of policies and measures (see Section 16.3.2).

Major constraints related to the capacity and resources needed to support the implementation of adaptation policies and processes include: access to (Lemos et al., 2010) and exchange of knowledge (e.g., adaptive capacity can be enhanced by linking indigenous and scientific knowledge; Valdivia, 2010); access to and quality of natural resources (López-Marrero, 2010); access to financial resources, especially for poor households (Satterthwaite, 2011b; Hickey and Weis, 2012; Rubin and Rossing, 2012), as well as for institutions (Pereira et al., 2009); access to technological resources (López-Marrero, 2010) and technical assistance (Guariguata, 2009; Eakin et al., 2011), as well as the fostering of public-private technology transfer (La Rovere et al., 2009; Ramirez-Villegas et al., 2012) and promotion of technical skills (Hickey and Weis, 2012); and social asset-based formation at the local level (Rubin and Rossing, 2012).

In terms of framing adaptation, as a constraint to affect the adaptation context, it is usually considered that a major barrier to adaptation is the perception of risks, and many studies focused on such an issue (e.g., Schlindwein et al., 2011). New studies (Adger et al., 2009) identified social limits to possible adaptation to climate change in relation with issues of values and ethics, risk, knowledge, and culture, even though such limits can evolve in time. Indeed, while being a necessary condition, perception may not be the main driver for initiating an adaptation process. As pointed out by Tucker et al. (2010) with a specific focus on CA, exogenous factors (economic, land tenure, cost, etc.) may actually strongly constrain the decision-making process involved in a possible adaptation process. In that sense, efficient governance and management are key components in the use of climate and non-climate information in the decision-making and adaptation process. As a consequence, it is difficult to describe adaptation without defining at which level it is thought. Indeed, though much effort is invested in national and regional policy initiatives, most of the final adaptation efforts will be local. National and international (transborder) governance is key to build adaptive capacity (Engle and Lemos, 2010) and therefore to strengthen (or weaken) local adaptation through efficient policies and delivery of resources. At a smaller scale (Agrawal, 2008), local institutions can strongly contribute to vulnerability reduction and adaptation. However, at all levels, the efficiency in national and local adaptation activities strongly depend on the capacity-building and information transmission to decision makers (Eakin and Lemos, 2006).

27.5 Interactions between Adaptation and Mitigation

Synergies between adaptation and mitigation strategies on the local level can be reached as a result of self-organization of communities in cooperatives (see, e.g., "The SouthSouthNorth Capacity Building Module on Poverty Reduction" (SSN Capacity Building Team, 2006), which manages recycling or renewable energy production, leading to an increase in energy availability, thus production capacity, and therefore new financial resources). Moreover, Venema and Cisse (2004) also support the development of decentralized renewable energy solutions for the growth of renewable energy in CA and SA (see also Section 27.3.6) next to a large infrastructure project (see their case studies for Argentina and Brazil).

In spite of their smaller size (individual or communitarian), these solutions offer adaptation and mitigation benefits. On one hand, fossil-based energy consumption is reduced, while energy availability is increased. On the other hand, reduction of energy precariousness is key in any development strategy. Thus, it allows local community and individuals to grow socially and economically, and therefore to reduce vulnerability, avoiding the poverty trap (UNDP, 2007), and to initiate an adaptation process based on non-fossil fuel energy sources. Such initiatives also depend on local and organizational leaderships (UN-HABITAT, 2011).

Such integrated strategies of income generation as adaptation measures as well as production of renewable energy are also identified for vulnerable, small farmers diversifying their crops toward crops for vegetable oil and biodiesel production in Brazil. Barriers identified concern capacity-building and logistical requirements, making policy tools, credit mechanism, and organization into cooperatives, and fostering necessary research (La Rovere et al., 2009). Other promising interactions of mitigation and adaptation are identified, for example, for the management of Brazilian tropical natural and planted forest (Guariguata, 2009).

At national and regional scales, CA and SA countries will require the allocation of human and financial resources to adapt to climate change. While resources are limited, too large an economic dependence of these countries to fossil fuels will reduce their adaptive capacity. The reduction in energy consumption and the integration of renewable energies in their energetic matrix is therefore a key issue for all these countries to sustain their development and growth and therefore increase their adaptive capacity (see also Section 27.3.6).

Reforestation and avoided deforestation are important practices that contribute to both mitigation and adaptation efforts in the region as in other parts of the world. Maintaining forest cover can provide a suite of environmental services including local climate regulation, water regulation, and reduced soil erosion—all of which can reduce the vulnerability of communities to variable climate (see Section 27.3.2.2; Vignola et al., 2009).

27.6. Case Studies

27.6.1. Hydropower

Hydropower is the main source of renewable energy in CA and SA (see Section 27.3.6). The region is second only to Asia in terms of hydropower energy generation in the world, displaying a 20% share of total annual generation and an average regional capacity factor of greater than 50% (SRREN Table 5-1; IPCC, 2011). As a result, the region has by far the largest proportion of electricity generated through hydropower facilities (Table 27-6). The hydropower proportion of total electricity production is greater than 40% in the region, and in some cases is near or close to 80%, as in the case of Brazil, Colombia, and Costa Rica (IEA, 2012). Although there is debate, especially in tropical environments, about GHG emissions from hydropower reservoirs (Fearnside and Pueyo, 2012), this form of electricity generation is often seen as a major contributor to mitigating GHG emissions worldwide (see IPCC, 2011; Kumar et al., 2011). But, on the other hand, hydropower is a climate-related sector, thus making it prone to the potential effects of changing climate conditions (see Section 27.3.1.1). In this regard the CA and SA region constitutes a unique example to study these relations between climate change mitigation and adaptation in relation to hydropower generation.

Diverse studies have analyzed the potential impacts of climate change on hydropower generation (Table 27-4). Maurer et al. (2009) studied future conditions for the Lempa River (El Salvador, Honduras, and Guatemala), showing a potential reduction in hydropower capacity of 33 to 53% by 2070–2099. A similar loss is expected for the Sinú-Caribe basin in Colombia where, despite a general projection of increased precipitation, losses due to evaporation enhancement reduce inflows to hydroelectric systems, thus reducing electricity generation up to 35% (Ospina Noreña et al., 2009a). Further studies (Ospina Noreña et al., 2011a,b) have estimated vulnerability indices for the hydropower sector in the same basin, and identified reservoir operation strategies to reduce this vulnerability. Overall reductions in hydropower generation capacity are also expected in Chile for the main hydropower generation river basins (Maule, Laja, and Biobio (ECLAC, 2009a; McPhee et al., 2010; Stehr et al., 2010)), and also in the Argentinean Limay River basin (Seoane and López, 2007). Ecuador, on the other hand, faces an increase in generation capacity associated with an increment in precipitation on its largest hydroelectric generator, the Paute River basin (Buytaert et al., 2010). Brazil, although being the country with the largest installed hydroelectric capacity in the region, still has unused generation capacity in sub-basins of the Amazon River (Soito and Freitas, 2011). However, future climate conditions plus environmental concerns pose an important challenge for the expansion of the system (Freitas and Soito, 2009; Andrade et al., 2012; Finer and Jenkins, 2012). According to de Lucena et al. (2009), hydropower systems in southern Brazil (most significantly the Parana River system) could face a slight increase in energy production under an A2 scenario. However, the rest of the country's hydropower system, especially those in NEB, could face a reduction in power generation, thus reducing the reliability of the whole system (de Lucena et al., 2009).

An obvious implication of the mentioned impacts is the need to replace the energy lost through alternative (see Section 27.3.6.2) or traditional sources. Adaptation measures have been studied for Brazil (de Lucena et al., 2010a), with results implying an increase in natural gas and sugarcane bagasse electricity generation on the order of 300 TWh, increase in operation costs on the order of US$7 billion annually, and US$50 billion in terms of investment costs by 2035. In Chile, the study by ECLAC (2009a) assumed that the loss in hydropower generation, on the order of 18 TWh for the 2011–2040 period (a little over 10% of actual total hydropower generation capacity) would be compensated by the least operating cost source available, coal-fired power plant, implying an increase of 2 MT CO_2-eq of total GHG emissions (emissions for the electricity sector in Chile totaled 25 MT CO_2-eq in 2009). Ospina Noreña (2011a,b) studied some adaptation options, such as changes in water use efficiency or demand growth that could mitigate the expected impacts on hydropower systems in the Colombian Sinú-Caribe River basin. Changes in seasonality and total availability could also increase complexities in the management of multiple-use dedicated basins in Peru (Juen et al., 2007; Condom et al., 2012), Chile (ECLAC, 2009a), and Argentina (Seoane and López, 2007), that could affect the relationship between different water users within a basin. It is worth noting that those regions that are projected to face an increase in streamflow and associated generation capacity, such as Ecuador or Costa Rica, also share difficulties in managing deforestation, erosion, and sedimentation which limits the useful life of reservoirs (see Section 27.3.1.1). In these cases it is important to consider these effects in future infrastructure operation (Ferreira and Teegavarapu, 2012) and planning, and also to enhance the ongoing process of recognizing the value of the relation between ecosystem services and hydropower system operations (Leguía et al., 2008) (see more on PES in Sections 27.3.2.2, 27.6.2).

27.6.2. Payment for Ecosystem Services

Payment for ecosystem services (PES) is commonly described as a set of transparent schemes for securing a well-defined ecosystem service (or a land use capable to secure that service) through conditional payments or compensations to voluntary providers (Engel et al., 2008; Tacconi, 2012). Van Noordwijk et al. (2012) provides a broader definition to PES by arguing that it encompasses three complementary approaches: (1) the one above, that is, commodification of predefined ecosystem services so that prices can be negotiated between buyers and sellers; plus (2) compensation for opportunities forgone voluntarily or by command and control decisions; and (3) coinvestment in environmental stewardships. Therefore, the terms *conservation agreements*, *conservation incentives*, and *community conservation* are often used as synonyms or as something

Table 27-7 | Cases of government-funded physiological-ecological simulation (PES) schemes in Central America and South America.

Countries	Level	Start	Name	Benefits	References
Brazil	Sub-national (Amazonas state)	2007	Bolsa Floresta	By 2008, 2700 traditional and indigenous families already benefitted: financial compensation and health assistance in exchange for zero deforestation in primary forests.	Viana (2008)
Costa Rica	National	1997	Fondo Nacional de Financiamiento Forestal	PES is a strong incentive for reforestation and, for agroforestry ecosystems alone, more than 7000 contracts have been set since 2003 and nearly 2 million trees planted.	Montagnini and Finney (2011)
Ecuador	National	2008	Socio-Bosque	By 2010, the program already included more than half a million hectares of natural ecosystems protected and has more than 60,000 beneficiaries.	De Koning et al. (2011)
Guatemala	National	1997	Programa de Incentivos Forestales	By 2009, the program included 4174 beneficiaries, who planted 94,151 hectares of forest. In addition, 155,790 hectares of natural forest were under protection with monetary incentives.	INE (2011)

different or broader than PES (Milne and Niesten, 2009; Cranford and Mourato, 2011). For simplicity, we refer to PES in its broadest sense (van Noordwijk et al., 2012).

Services subjected to such types of agreements often include regulation of freshwater flows, carbon storage, provision of habitat for biodiversity, and scenic beauty (de Koning et al., 2011; Montagnini and Finney, 2011). Because the ecosystems that provide the services are mostly privately owned, policies often aim at supporting landowners to maintain the provision of services over time (Kemkes et al., 2010). Irrespective of the debate as to whether payments or compensations should be designed to focus on actions or results (Gibbons et al., 2011), experiences in Colombia, Costa Rica, and Nicaragua show that PES can finance conservation, ecosystem restoration, and better land use practices (Montagnini and Finney, 2011; see also Table 27-5). However, based on examples from Ecuador and Guatemala, Southgate et al. (2010) argue that uniformity of payment for beneficiaries can be inefficient if recipients accept less compensation in return for conservation measures, or if recipients that promote greater environmental gains receive only the prevailing payment. Other setbacks to PES schemes might include cases where there is a perception of commoditization of nature and its intangible values (e.g., Bolivia, Cuba, Ecuador, and Venezuela); other cases where mechanisms are inefficient to reduce poverty; and slowness to build trust between buyers and sellers, as well as gender and land tenure issues that might arise (Asquith et al., 2008; Peterson et al., 2010; Balvanera et al., 2012; van Noordwijk et al., 2012). Table 27-7 lists select examples of PES schemes in Latin America, with a more complete and detailed list given in Balvanera et al. (2012).

The PES concept (or "fishing agreements") also applies to coastal and marine areas, although only a few cases have been reported. Begossi (2011) argues that this is due to three factors: origin (the mechanism was originally designed for forests), monitoring (marine resources such as fish are more difficult to monitor than terrestrial resources), and definition of resource boundaries in offshore water. One example of a compensation mechanism in the region is the so-called *defeso*, in Brazil. It consists of a period (reproductive season) when fishing is forbidden by the government and fishermen receive a financial compensation. It applies to shrimp, lobster, and both marine and freshwater fisheries (Begossi et al., 2011).

27.7. Data and Research Gaps

The scarcity of and difficulty in obtaining high-resolution, high quality, and continuous climate, oceanic, and hydrological data, together with availability of only very few complete regional studies, pose challenges for the region to address changes in climate variability and the identification of trends in extremes, in particular for CA. This situation hampers studies on frequency and variability of extremes, as well as impacts and vulnerability analyses of the present and future climates, and the development of vulnerability assessments and adaptation actions.

Related to observed impacts in most sectors, there is an imbalance in information availability among countries. While more studies have been performed for Brazil, southern SA, and SESA region, much less are available for CA and for some regions of tropical SA. An additional problem is poor dissemination of results in peer-reviewed publications because most information is available only as grey literature. There is a need for studies focused on current impacts and vulnerabilities across sectors throughout CA and SA, with emphasis on extremes to improve risk management assessments.

The complex interactions between climate and non-climate drivers make the assessment of impacts and projections difficult, as is the case for water availability and streamflows owing to current and potential deforestation, overfishing and pollution regarding the impacts on fisheries, or impacts on hydroenergy production. The lack of interdisciplinary integrated studies limits our understanding of the complex interactions between natural and socioeconomic systems. In addition, accelerating deforestation and land use changes, as well as changes in economic conditions, impose a continuous need for updated and available data sets that feed basic and applied studies.

To address the global challenge of food security and food quality, both important issues in CA and SA, investment in scientific agricultural knowledge needs to be reinforced, mainly with regard to the integration of agriculture with organic production, and the integration of food and bioenergy production. It is necessary to consider ethical aspects when the competition for food and bioenergy production is analyzed to identify which activity is most important at a given location and time and whether bioenergy production would affect food security for a particular population.

SLR and coastal erosion are also relevant issues; the lack of comparable measurements of SLR in CA and SA make the present and future integrated assessment of the impacts of SLR in the region difficult. Of local and global importance will be improving our understanding of the physical oceanic processes, in particular of the Humboldt Current system flowing along the west coast of SA, which is one of the most productive systems worldwide.

More information and research about the impacts of climate variability and change on human health is needed. One problem is the difficulty in accessing health data that are not always archived and ready to be used in integrated studies. Another need refers to building the necessary critical mass of transdisciplinary scientists to tackle the climate change-human health problems in the region. The prevailing gaps in scientific knowledge hamper the implementation of adaptation strategies, thus demanding a review of research priorities toward better disease control. With the aim of further studying the health impacts of climate change and identifying resilience, mitigation, and adaptation strategies, South-South cooperation and multidisciplinary research are considered to be relevant priorities.

In spite of the uncertainty that stems from global and regional climatic projections, the region needs to act in preparation for a possible increase in climate variability and in extremes. It is necessary to undertake research activities leading to public policies to assist societies in coping with current climate variability, such as, for example, risk assessment and risk management. Another important aspect since AR4 is the improvement of climate modeling and the generation of high-resolution climate scenarios, which in countries in CA and SA resulted in the first integrated regional studies on impacts and vulnerability assessments of climate change focusing on sectors such as agriculture, energy, and human health.

Research on adaptation and the scientific understanding of the various processes and determinants of adaptive capacity is also mandatory for the region, with particular emphasis on increasing adaptation capacity involving the traditional knowledge of ancestral cultures and how this knowledge is transmitted. Linking indigenous knowledge with scientific knowledge is important. The concept of "mother earth" (madre tierra in Spanish) as a living system has been mentioned in recent years, as a key sacred entity on the view of indigenous nations and as a system that may be affected and also resilient to climate change. Although some adaptation processes have been initiated in recent years dealing with this and other indigenous knowledge, there is only very limited scientific literature discussing these subjects so far.

The research agenda needs to address vulnerability and foster adaptation in the region, encompassing an inclusion of the regions' researchers and focusing also on governance structures and action-oriented research that addresses resource distribution inequities.

Regional and international partnerships, and research networks and programs, have allowed linking those programs with local strategies for adaptation and mitigation, also providing opportunities to address research gaps and exchange among researchers. Examples are the European Union funded projects CLARIS LPB (La Plata Basin) in SESA, and AMAZALERT in Amazonia. Other important initiatives come from the Interamerican Institute for Global Change Research (IAI), World Health Organization (WHO), Global Environment Facility (GEF), Inter-American Development Bank (IDB), Economic Commission for Latin America and the Caribbean (ECLAC, CEPAL), La Red, and BirdLife International, among others. The same holds for local international networks such as the International Council for Local Environmental Initiatives (ICLEI) or C40, of which CA and SA cities form part. The weADAPT initiative is a good example on how CA and SA practitioners, researchers, and policy makers can have access to credible, high-quality information and to share experiences and lessons learned in other regions of the world.

27.8. Conclusions

CA and SA harbor unique ecosystems and maximum biodiversity, with a variety of eco-climatic gradients rapidly changing from development initiatives. Agricultural and beef production as well as bioenergy crops are on the rise, mostly by expanding agricultural frontiers. Poverty and inequality are decreasing, but at a slow pace. Socioeconomic development shows a high level of heterogeneity and a very unequal income distribution, resulting in high vulnerability to climatic conditions. There is still a high and persistent level of poverty in most countries (45% for CA and 30% for SA for year 2010) in spite of the sustained economic growth observed in the last decade.

The IPCC AR4 and SREX reports contain ample evidence of increase in extreme climate events in CA and SA. During 2000–2013, 613 weather and climate extreme events led to 13,883 fatalities and 53.8 million people affected, with estimated losses of US$52.3 billion. During 2000–2009, 39 hurricanes occurred in the CA-Caribbean basin compared to 15 and 9 in the decade of 1980 and 1990, respectively. In SESA, more frequent and intense rainfall extremes have favored an increase in the occurrence of flash floods and landslides. In Amazonia extreme droughts were reported in 2005 and 2010, and record floods were observed in 2009 and 2012. In 2012–2013 an extreme drought affected NEB.

While warming occurred in most of CA and SA, cooling was detected off the coast of southern Peru and Chile. There is growing evidence that Andean glaciers (both tropical and extratropical) are retreating in response to warming trends. Increases in precipitation were registered in SESA, CA, and the NAMS regions, while decreases were observed in southern Chile, and a slight decrease in NEB after the middle 1970s. In CA a gradual delay of the beginning of the rainfall season has been observed. SLR varied from 2 to 7 mm yr^{-1} between 1950 and 2008 in CA and SA, which is a reason for concern because a large proportion of the population of the region lives by the coast.

Land use and land cover change are key drivers of regional environmental change in SA and CA. Natural ecosystems are affected by climate variability/change and land use change. Deforestation, land degradation, and biodiversity loss are attributed mainly to increased extensive agriculture for traditional export activities and bioenergy crops. Agricultural expansion has affected fragile ecosystems, causing severe environmental degradation and reducing the environmental services provided by these ecosystems. Deforestation has intensified the process of land degradation, increasing the vulnerability of communities exposed to floods, landslides, and droughts. Plant species are rapidly declining in CA and SA, with a high percentage of rapidly declining amphibian species. However, the region has still large extensions of natural vegetation cover, with the Amazon being the main example. Ecosystem-based adaptation practices, such as the establishment of protected areas and their effective management, conservation agreements, community management of natural areas, and payment for ecosystem services are increasingly more common across the region.

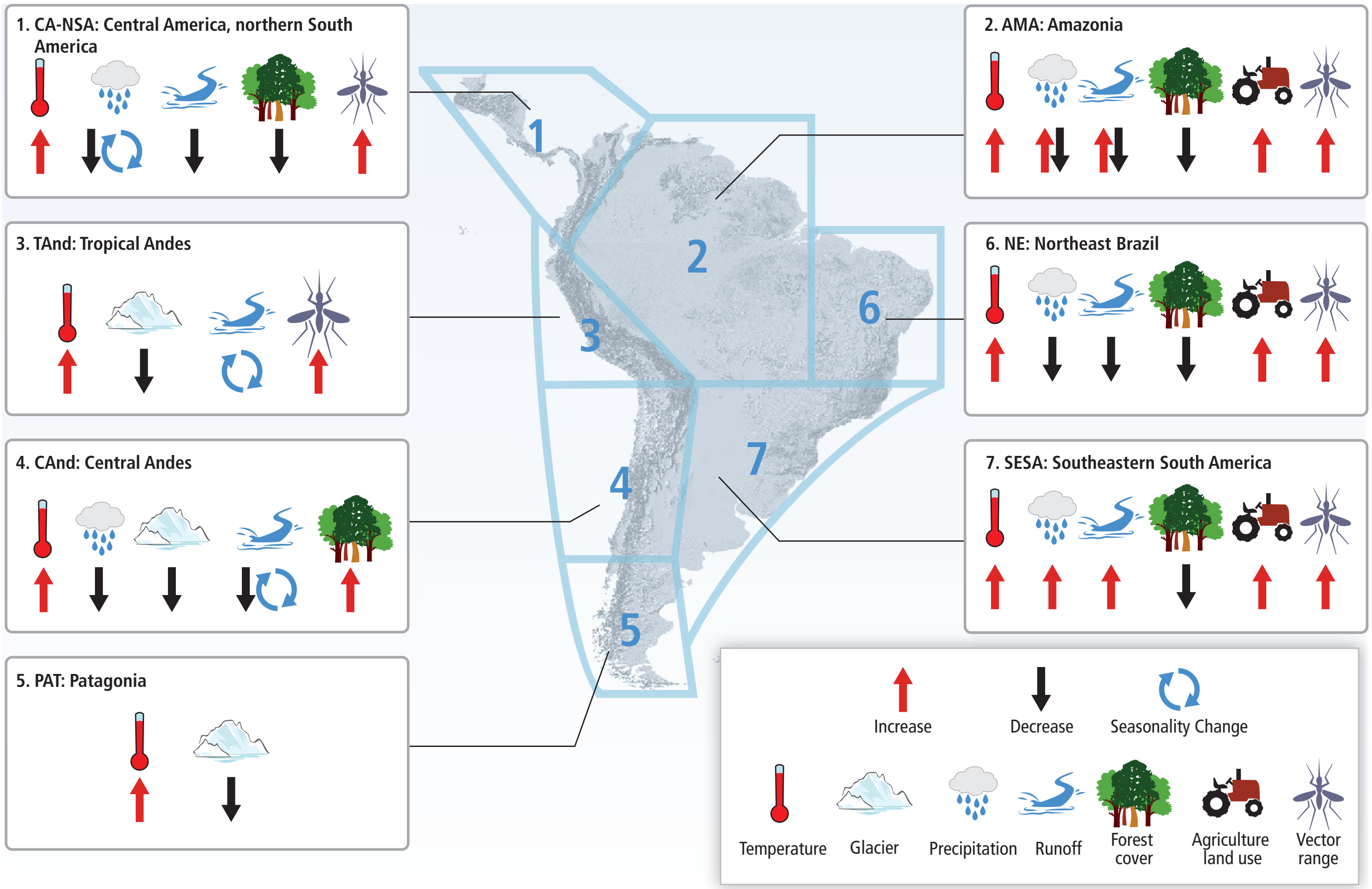

Figure 27-7 | Summary of observed changes in climate and other environmental factors in representative regions of Central and South America. The boundaries of the regions in the map are conceptual (neither geographic nor political precision). Information and references to changes provided are presented in different sections of the chapter.

Figure 27-7 summarizes of some of the main observed trends in global environmental change drivers across different representative regions of CA and SA. Changes in climate and non-climate drivers have to be compounded with other socioeconomic related trends, such as the rapid urbanization experienced in the region.

Some observed impacts on human and natural systems can be directly or indirectly attributed to human influences (see also Figure 27-8):

- Changes in river flow variability in the Amazon River during the last 2 decades, robust positive trends in streamflow in sub-basins of the La Plata River basin, and increased dryness for most of the river basins in west coast of South America during the last 50 years
- Reduction in tropical glaciers and ice fields in extratropical and tropical Andes over the second half of the 20th century that can be attributed to an increase in temperature
- Coastal erosion, bleaching of coral reefs in the coast of CA, and reduction in fisheries stock
- Increase in agricultural yield in SESA, and shift in agricultural zoning (significant expansion of agricultural areas, mainly in climatically marginal regions)
- Increase in frequency and extension of dengue fever, yellow fever, and malaria.

However, for some impacts the number of concluding studies is still insufficient, leading to low levels of confidence for attribution to human influences.

By the end of the century, the CMIP5-derived projections for RCP8.5 yielded: CA – mean annual warming of 2.5°C (range: 1.5°C to 5.0°C), mean rainfall reduction of 10% (range: –25% to +10%), and reduction in summertime precipitation; SA – mean warming of 4°C (range: 2.0°C to 5.0°C), with rainfall reduction up to 15% in tropical SA east of the Andes, and an increase of about 15 to 20% in SESA and in other regions of the continent, and increases in warm days and nights *very likely* to occur in most of SA; SESA – increases in heavy precipitation, and increases in dry spell in northeastern SA. However, there is some degree of uncertainty in climate change projections for regions, particularly for rainfall in CA and tropical SA.

Current vulnerability in terms of water supply in the semi-arid zones and the tropical Andes is expected to increase even further due to climate change. This would be exacerbated by the expected glacier retreat, precipitation reduction, and increased evapotranspiration demands as expected in the semi-arid regions of CA and SA. These scenarios would affect water supply for large cities, small communities, food production, and hydropower generation. There is a need for reassessing current practices to reduce the mismatch between water supply and demand to reduce future vulnerability, and to implement constitutional and legal reforms toward more efficient and effective water resources management.

SLR due to climate change and human activities on coastal and marine ecosystems pose threats to fish stocks, corals, mangroves, recreation

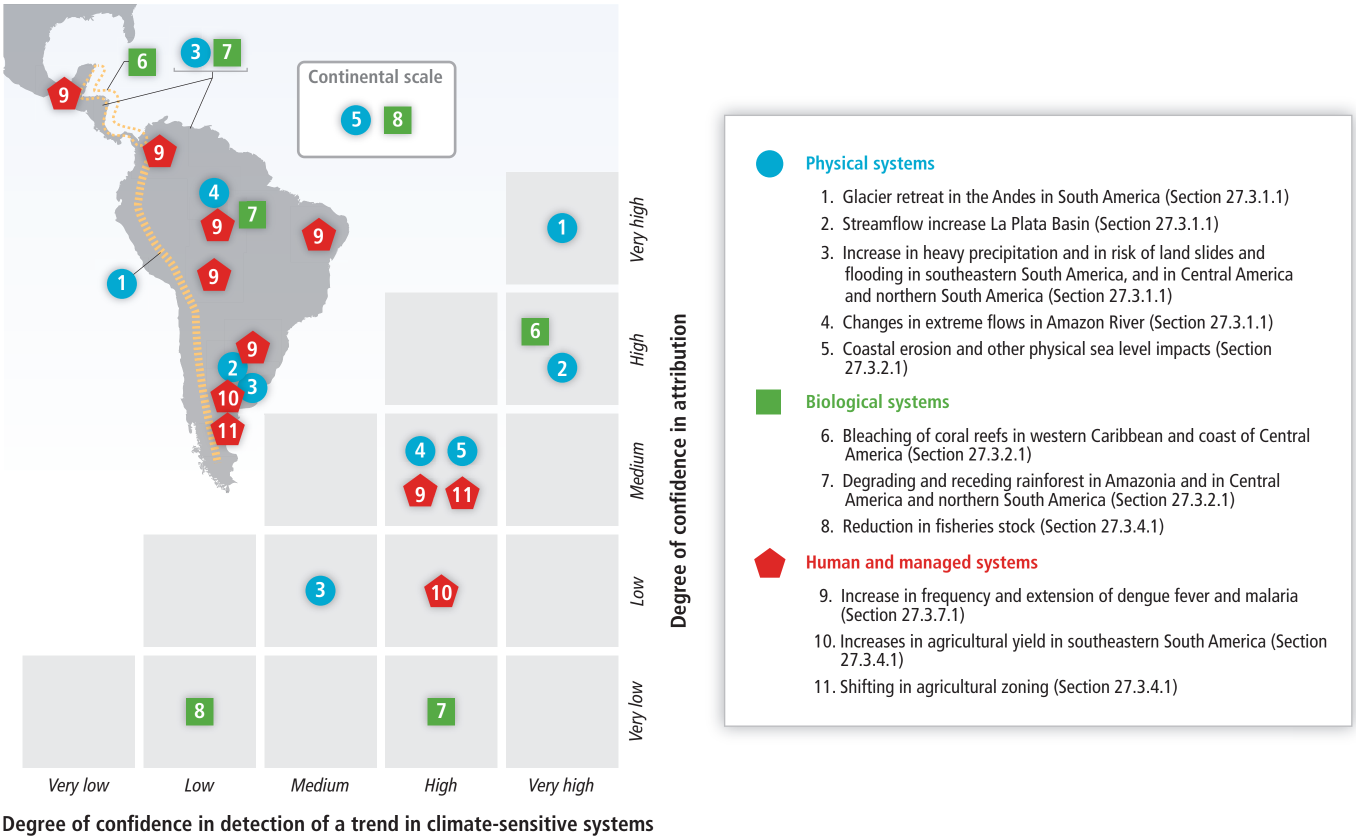

Figure 27-8 | Observed impacts of climate variations and attribution of causes to climate change in Central and South America.

and tourism, and diseases control in CA and SA. Coral reefs, mangroves, fisheries, and other benthic marine invertebrates that provide key ecosystem services, such as nutrient cycling, water quality regulation, and herbivory, are also threatened by climate change. It is possible that the Mesoamerican coral reef will collapse by mid-century (between 2050 and 2070), causing major economic and environmental losses. In the southwestern Atlantic coast, eastern Brazilian reefs might suffer a massive coral cover decline in the next 50 years. In the Rio de La Plata area extreme flooding events may become more frequent because return periods are decreasing, and urban coastal areas in the eastern coast will be particularly affected. Beach erosion is expected to increase in southern Brazil and in scattered areas at the Pacific coast.

Urban populations in CA and SA face diverse social, political, economic, and environmental risks in daily life, and climate change will add a new dimension to these risks. Because urban development remains fragile in many cases, with weak planning responses, climate change can compound existing challenges, for example, water supply in cities from glacier, snowmelt, and paramos related runoff in the Andes (Lima, La Paz/El Alto, Santiago de Chile, Bogotá), flooding in several cities such as São Paulo and Buenos Aires, and health-related challenges in many cities of the region.

Climate change will affect individual species and biotic interactions. Vertebrate fauna will suffer major species losses especially in high-altitude areas; elevational specialists might be particularly vulnerable because of their small geographic ranges and high energetic requirements. Freshwater fisheries can suffer alterations in physiology and life histories. In addition, modifications in phenology, structure of ecological networks, predator-prey interactions, and non-trophic interactions among organisms will affect biotic interactions. Shifts in biotic interactions are expected to have negative consequences on biodiversity and ecosystem services in High Andean ecosystems. Although in the region biodiversity conservation is largely confined to protected areas, it is expected that many species and vegetational types will lose representativeness inside such protected areas.

Changes in food production and food security are expected to have great spatial variability, with a wide range of uncertainty mainly related to climate and crop models. In SESA average productivity could be sustained or increased until the mid-century, although interannual and decadal climate variability is *likely* to impose important damages. In other regions such as NEB, CA, and some Andean countries agricultural productivity could decrease in the short term, threatening the food security of the poorest population. The expansion of pastures and croplands is expected to continue in the coming years, particularly from an increasing global demand for food and biofuels. The great challenge for CA and SA will be to increase the food and bioenergy production and at the same time sustain the environmental quality in a scenario of climate change.

Renewable energy provides great potential for adaptation and mitigation. Hydropower is currently the main source of renewable energy in CA and SA, followed by biofuels. SESA is one of the main sources of production of the feedstocks for biofuel production, mainly with sugarcane and soybean, and future climate conditions may lead to an increase in productivity and production. Advances in second-generation biofuels will be important as a measure of adaptation, as they have the potential to increase biofuel productivity. In spite of the large amount of arable land available, the expansion of biofuels might have some direct and indirect land use change effects, producing teleconnections that could lead to deforestation of native tropical forests and loss of employment in some countries. This might also affect food security.

Changes in weather and climatic patterns are negatively affecting human health in CA and SA, by increasing morbidity, mortality, and disabilities, and through the emergence of diseases in previously non-endemic regions. Multiple factors increase the region's vulnerability to climate change: precarious health systems; malnutrition; inadequate water and sanitation services; population growth; poor waste collection and treatment systems; air, soil, and water pollution; food in poor regions; lack of social participation; and inadequate governance. Vulnerabilities vary with geography, age, gender, race, ethnicity, and socioeconomic status, and are rising in large cities. Climate change and variability may exacerbate current and future risks to health.

Climate change will bring modifications to environmental conditions in space and time, and the frequency and intensity of weather and climate processes. In many CA and SA countries, a first step toward adaptation to climate change is to reduce the vulnerability to present climate, taking into account future potential impacts, particularly of weather and climate extremes. Long-term planning and the related human and financial resource needs may be seen as conflicting with present social deficit in the welfare of the CA and SA population. Such conditions weaken the importance of adaptation planning to climate change on the political agenda. Currently, there are few experiences on synergies between development, adaptation, and mitigation planning, which can help local communities and governments to allocate available resources in the design of strategies to reduce vulnerability and develop adaptation measures. Facing a new climate system and, in particular, the exacerbation of extreme events, will call for new ways to manage human and natural systems for achieving sustainable development.

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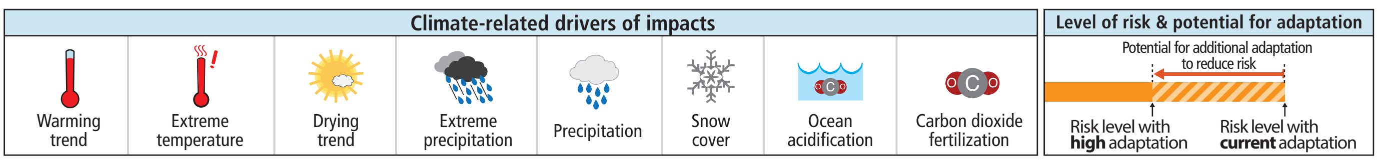
Table 27-8 | Key risks from climate change and the potential for risk reduction through mitigation and adaptation.



Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Water availability in semi-arid and glacier-melt-dependent regions and Central America; flooding and landslides in urban and rural areas due to extreme precipitation (*high confidence*) [27.3]	• Integrated water resource management • Urban and rural flood management (including infrastructure), early warning systems, better weather and runoff forecasts, and infectious disease control		Present	Very low / Medium / Very high
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	
			Long term (2080–2100) 4°C	
CA coral reef bleaching (*high confidence*) [27.3.3]	Limited evidence for autonomous genetic adaptation of corals; other adaptation options are limited to reducing other stresses, mainly enhancing water quality and limiting pressures from tourism and fishing.		Present	Very low / Medium / Very high
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	
			Long term (2080–2100) 4°C	
Decreased food production and food quality (*medium confidence*) [27.3]	• Development of new crop varieties more adapted to climate change (temperature and drought) • Offsetting of human and animal health impacts of reduced food quality • Offsetting of economic impacts of land-use change • Strengthening traditional indigenous knowledge systems and practices		Present	Very low / Medium / Very high
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	
			Long term (2080–2100) 4°C	
Spread of vector-borne diseases in altitude and latitude (*high confidence*) [27.3]	• Development of early warning systems for disease control and mitigation based on climatic and other relevant inputs. Many factors augment vulnerability. • Establishing programs to extend basic public health services		Present	Very low / Medium / Very high
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	not available
			Long term (2080–2100) 4°C	not available

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