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Latin America

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EXECUTIVE SUMMARY

The Latin America region is remarkably heterogeneous in terms of climate, ecosystems, human population distribution, and cultural traditions. Land-use changes have become a major force driving ecosystem changes. Complex climatic patterns, which result in part from interactions of atmospheric flow with topography, intermingled with land-use and land-cover change, make it difficult to identify common patterns of vulnerability to climate change in the region. Water resources, ecosystems, agriculture and plantation forestry, sea-level rise, and human health may be considered the most important among the various sectors that may be impacted by climate change.

Climate, Extreme Events, and Water Resources

In most of Latin America, there are no clear long-term tendencies in mean surface temperature. Some changes in regional atmospheric circulation have been detected. For instance, the south Atlantic anticyclone has intensified, and the subtropical jet stream in South America has shifted south. These phenomena may be a sign of changes associated with climate change as they already are impacted by the El Niño-Southern Oscillation (ENSO) phenomena and extreme events.

The cryosphere in Latin America, which is composed of glaciers in the high Andes and three major ice areas in southern South America, may be severely affected by global warming. It has been well established that glaciers in Latin America, particularly along the tropical Andes, have receded in recent decades. Glaciers contribute to streamflow in rivers of semi-arid and arid areas of South America. Streamflows in Andean rivers—for example, in northwest Peru—exhibit tendencies that may be related to glacial extent changes before and after the mid-1970s. However, there also is evidence that rainfall and river flows in other regions of Latin America correspond only to interdecadal variability in the hydrological cycle. For instance, rainfall and streamflow in Amazonia and northeast Brazil exhibit interdecadal variability linked to Pacific and Atlantic Ocean influences. Warming in high mountains also could affect mountain sports and tourist activities, which represent an important source of income in the economies of some countries in the region.

At a subregional level, precipitation trends in Latin America vary. Precipitation trends depend on the location and the length of the time series under study. For instance, negative trends in some parts of Central America (e.g., Nicaragua) contrast with positive trends in northeastern Argentina, southern Brazil, and northwestern Mexico. Other regions, such as central-western Argentina, do not show well-defined trends. This suggests, for instance, an increase in precipitation in some regions of the mid-latitude Americas.

The Amazon River—by far the world's largest river in terms of streamflow—plays an important role in the water cycle and water balance of much of South America. Several model studies and field experiments show that about 50% of the rainfall in the region originates as water recycled in the forest. In the Amazon region, even small changes in evapotranspiration affect water vapor fluxes. Therefore, deforestation is likely to reduce precipitation because of a decrease in evapotranspiration, leading to important runoff losses in areas within and beyond this basin. Any reductions in rainfall would affect not only Amazonia but also Brazil's central-south region, where most of the country's agriculture and silviculture are located. However, with the current rate of deforestation of no more than 10% in Amazonia as a whole, discharge observations across the basin do not exhibit, to date, any significant trends.

Although it is expected that tropical storms (e.g., tropical cyclones) will increase their peak intensity under global warming (see Table 3-10), only some hints of such intensification in the tropical cyclones affecting the Americas have been detected. Some studies based on model experiments suggest that under climate change the hydrological cycle will be more intense, with changes in the distribution of extreme heavy rainfall, wet spells, and dry spells. Frequent severe droughts in Mexico during the past decade coincide with some of these model findings. Even though it is uncertain how global warming may affect the frequency and intensity of some extreme events, the infrequent overlapping of hydrological and weather/climate events historically have given rise to disasters, whose frequency may be enhanced by such warming.

El Niño

It also has been suggested that under climate change, more El Niño-like mean conditions will be experienced. El Niño differentially influences precipitation and temperature in different parts of the region; for example, it is related to dry conditions in northern northeast Brazil, northern Amazonia, and the Peruvian-Bolivian Altiplano. Southern Brazil and northwest Peru exhibit anomalously wet conditions during these periods. In Mexico and the Caribbean coast of Central America, there is compelling evidence of more winter precipitation and less summer precipitation during El Niño. Some of the most severe droughts in Mexico in recent decades have occurred during

El Niño years. During the 1997–1998 El Niño event, droughts occurred in Amazonia, Mexico, and Central America, favoring forest fires. Under climate change conditions, the number of forest fires may increase.

Natural Ecosystems

Latin America contains a large percentage of the world's biodiversity, and climate change could accelerate losses in biodiversity that already are occurring. Some adverse impacts on species that can be related to regional changes in climate have been observed. Studies show that climatic changes already are affecting frogs and small mammals in Central America. The tropical forests play an important role in the hydrological cycle of much of South America. Several model studies and field experiments show that a large part of the rainfall in the region originates as water recycled in the forest. Large-scale deforestation is likely to result in increased surface temperatures, decreased evapotranspiration, and reduced precipitation. Forest fragmentation and degradation has led to increased vulnerability of forests to fire. Global warming and regional climate change resulting from land-cover change may be acting synergistically to exacerbate stress over the region's tropical ecosystems.

Mountain ranges and plateaus play an important role in determining not only the Latin America climate and its hydrological cycle but also its large biodiversity. Mountains constitute source regions of major rivers such as the Amazon, the Parana, and the Orinoco. These river basins represent important habitats of biological diversity and endemism and are highly vulnerable to extreme climate conditions.

On decadal to centennial time scales, changes in precipitation and runoff may have significant impacts on mangrove forest communities. Sea-level rise would eliminate mangrove habitat at an approximate rate of 1% yr^{-1}. The rate is much faster in the Caribbean mainland (approximately 1.7% yr^{-1}). This problem is causing a decline in some of the region's fisheries at a similar rate because most commercial shellfish use mangroves as nurseries or refuges. Coastal inundation stemming from sea-level rise or flatland flooding resulting from climate change therefore may seriously affect mangrove ecology and associated human economy.

Agriculture

Agricultural lands (excluding pastures) represent approximately 19% of the total area of Latin America. For the past 40 years, the contribution of agriculture to the gross domestic product (GDP) of Latin American countries has been on the order of 10%. Therefore, this economic sector remains a key element of the regional economy. An important aspect of this sector is that a large percentage (30–40%) of the economically active population works in this sector. Agriculture also is an important element for the food security of the poorest sectors of the population. Under climate change conditions, subsistence farming could be severely threatened in some parts of Latin America, such as northeastern Brazil.

Studies in Argentina, Brazil, Chile, Mexico, and Uruguay based on general circulation models (GCMs) and crop models project decreased yields in several crops (e.g., maize, wheat, barley, grapes), even when the direct effect of carbon dioxide (CO_2) fertilization and the implementation of moderate adaptation measures at the farm level are considered. It is likely that increases in temperature will reduce crop yields in the region by shortening the crop cycle. However, the lack of consistency in the various GCM precipitation scenarios makes it difficult to have a precise scenario for crop production under climate change, even when the relationships between precipitation and crop yields are well known. Increased temperature, ultraviolet radiation, sea-level rise, and changes in pest ecology may threaten food production as well (e.g., in Argentina). Climate change may reduce silvicultural yields as a result of changes in water availability during the dry season.

Human Health

The magnitude of the impacts of climate change on health in Latin America primarily depends on the size, density, location, and wealth of the population. It has been established that exposure to heat or cold waves has an influence on mortality rates in risk groups in the region. The projected increase in temperature in polluted cities, such as Mexico City or Santiago, may have an influence on human health. There is evidence that the geographical distributions of vector-borne diseases (e.g., malaria, dengue) in Brazil, Colombia, Argentina, and Honduras and infectious diseases (e.g., cholera, meningitis) in Peru and Cuba change when temperature and precipitation increase. The exact distribution of these diseases, however, is not clear.

It is likely that extreme weather events will increase death and morbidity rates (injuries, infectious diseases, social problems, and damage to sanitary infrastructure), as during the heavy rains in Mexico in 1999 or in Venezuela in 1999. On longer time scales, El Niño and La Niña cause changes in disease vector populations and the incidence of water-borne diseases in Brazil, Peru, Bolivia, Argentina, and Venezuela. Extreme climate events appear to affect the incidence of allergies in Mexico. Some economic and health problems could be exacerbated in critical areas, fostering migrations from rural and small urban settlements into major cities and giving rise to additional stress at the national level and, at times, adversely affecting international relations between neighboring countries. Therefore, under climate change conditions the risks for human health in Latin America may increase.

Adaptation Potential and Vulnerability

The economy of Latin American countries can be severely affected by extremes of natural climate variability. There were more than 700 natural disasters in the region between 1980 and 1998. For instance, Hurricane Mitch in 1998 resulted in economic losses of approximately 40 and 70% of the gross national product (GNP) in Nicaragua and Honduras, respectively. Poverty and unequal distribution of wealth may increase as a result of the negative effects of climate change.

Trade agreements are becoming increasingly important for Latin American economies. In principle, they have been designed mainly to speed up socioeconomic development. However, various elements that relate to environmental issues gradually are being introduced into these agreements, including provisions related to climate change. Environmental issues are beginning to be reflected in the environmental legislation in the region. For instance, environmental impact assessments are now required in most project developments.

Although climate change may bring benefits for certain regions of Latin America, increasing environmental deterioration, combined with changes in water availability and agricultural lands, may reduce these benefits to a negligible level. The adaptive capacity of socioeconomic systems in Latin America is very low, particularly with respect to extreme climate events, and vulnerability is high.

14.1. The Latin America Region

14.1.1. What is Unique about the Latin America Region?

The Latin American population will increase to 838 million by the year 2050. Annual population growth rates will decrease from 1.68%, in the period 1995–2000, to an estimated 0.51% in the period 2040–2050, according to the medium prospect of the United Nations (Nawata, 1999). This signifies that the population explosion will continue, even if a decerease in population growth rates were possible. One of the critical difficulties caused by growing population is the problem of nutrition and availability of food. Global food supply is expected to meet the overall needs of the growing world population, but significant regional variation in crop yields as a result of climate change (Rosenzweig *et al.*, 1993) could lead to an increased risk of hunger for an additional 50 million people by the year 2050. Because most Latin American countries' economies depend on agricultural productivity, the issue of regional variation in crop yields is very relevant for the region.

The area of the Latin American region is approximately 19.93 million km^2—double that of Europe, but smaller than that of North America, Asia, or Africa. Latin America includes all of the continental countries of the Americas, from Mexico to Chile and Argentina, as well as adjacent seas (Canziani *et al*., 1998). Even though the region has a predominantly southern location, Latin America also has a presence in the northern hemisphere, including Mexico, Central America, the Guyanas, Suriname, Venezuela, and parts of Colombia, Ecuador, and Brazil.

Latin America's orographical systems present a predominant north-south orientation, extending from the ranges of Mexico and Central America to the southern Andes. These features divide the region into two contrasting but interdependent geosystems, influencing the climatic and hydrological patterns and making primary productivity a direct dependent variable of the aforementioned environmental factors (Lieth, 1976).

These conditions initially led to a prevalence of agricultural activities near coastlines. From the end of the 19th century and the arrival of European migrations, these activities were extended to inner valleys and plateaus. Pre-Colombian cultures, however, had developed many of their community farming activities in the high plateaus, where the largest proportion of Latin America indigenous communities still are settled.

Mountain ranges and high plateaus play an important role in determining local climates that are conditioned by altitude and orientation, which in turn enhance biological diversity. Agricultural diversification also is coupled to habitat heterogeneity through varying crop species and agricultural time schedules. Morello (1976) has reported the way in which hunting, fishing, cattle and sheep grazing, and cropping activities are correlated to discontinued habitats along the altitudinal gradients in the humid tropical Andes in Colombia. Similar patterns have been reported for the Andes of Ecuador (Cornik and Kirby, 1981). Mountain ranges in Latin America also should be considered genetic/germoplasm banks for a wide variety of plants cultivated since the pre-Hispanic period, as well as for domesticated animals (llama, alpaca) and their wild relatives. The success of agriculture in the Andes is based on the genetic variability of plant populations and on the people themselves who have acquired the proper technology after centuries of agricultural practices. This genetic variability has resulted not only in a high number of cultivated species but also in a striking diversity of cultivars and genotypes adapted to the environmental heterogeneity of the mountain ecosystems (Blanco Galdós, 1981).

Each valley or mountain range has its own characteristics, especially in the tropical Andes, making the area one of the most diverse physical and biological mosaics in the world. At the same time, local populations in the Andes have developed appropriate technologies that are applicable in highlands agriculture; these technological reservoirs are comparable only to those existing in the high plateaus of Asia (Morello, 1984)

Earthquakes, volcanoes, and tectonic movements are common all over Latin America. Some of these events may be catastrophic because urban and rural settlements are likely to be devastated, but some may have positive effects. For example, floods in Argentina, which originate in the high Andean watersheds, have devastating effects on cultivated valleys. However, aquifers previously exhausted through alfalfa irrigation become recharged, and salinized soils are washed. Furthermore, volcanic eruption generates soil enrichment, which nourishes a wide range of crops, including coffee in Central America and Colombia.

Latin America contains a large variety of climates as a result of its geographical configuration. The climatic spectrum ranges from cold, icy high elevations, with some of the few glaciers still found in the tropics, to temperate and tropical climate. The region also has large arid and semi-arid areas. One of the most important characteristics of Latin America from the climatic point of view is its large sensitivity and vulnerability to ENSO events. From northern Mexico to Tierra del Fuego, every country in the continent exhibits anomalous conditions associated with ENSO.

The region also hosts the largest pluvial forest in the world: 7.5 million km^2 constitute Amazonia, of which 6.12 million km^2 are within the Amazon basin. The average rainfall in the Amazon basin is about 2,300 mm yr^{-1}, with real evaporation estimated at 1,146–1,260 mm yr^1. The Amazon is undoubtedly the world's largest river in terms of its outflow, with an average annual flow rate of 209,000 m^3 sec^{-1}. The Amazon, the Parana-Plata, and the Orinoco carry into the Atlantic Ocean more than 30% of the freshwater of the world. However, these water resources are poorly distributed, and extensive zones have extremely limited water resources.

Latin America hosts one of the largest terrestrial and marine biological diversities in the world. South America has the largest fish catch on the eastern Pacific. There is an important flow of krill and other plankton species as a result of cold sea currents on both sides of the southern tip of South America. A combination of the prevailing atmospheric and oceanic circulation defines the climate and the land and sea productivity of the region. This explains the actual distribution of human settlements and the availability of basic services (e.g., water supply).

Overall, the health profile of the Latin American population can be classified as undergoing a slow epidemiological transition. At one extreme of the spectrum there is a high incidence of (and mortality from) chronic noninfectious diseases such as cardiovascular problems and cancer, which predominate in large metropolitan areas. On the other hand, infectious diseases still impose a heavy burden on the poverty-stricken parts of the population. The reasons for this dichotomy are two-fold: uneven socioeconomic development within countries and the extreme diversity of regional environments.

Latin America (and the Caribbean) has the greatest disparity in income distribution in the world. A mere 5% of the population receives 25% of all national income, and the top 10% receive 40%. Such proportions are comparable only to those found in some African countries (IDB, 1999).

Many problems that have affected Latin America adversely are now showing a wood-saw type of change, with some temporary improvements and downfalls. However, in some countries of the region, improvement in the macroeconomy is being observed, in spite of the negative impact from recent developments in Asia and some countries of the region (Mexico and Brazil). Improvement currently observed in the economies of Mexico, Brazil, Chile, and Argentina does not reflect the meso- and microeconomies net deterioration in the living standards of rural and peri-rural urban areas. The middle class, which had become a sign of progress in several countries, also is adversely affected. This situation, added to the effect of extreme events, has exacerbated migration toward richer cities and countries with relatively better economies. Shantytowns have grown steadily around big cities, and poverty belts have even tripled. Their location in flood-prone valleys and unstable hills results in a lack of potable water and sanitation services, which is posing a serious threat to these cities.

Cultural (language, traditions, religion), economic (degree of development, economic systems, wealth distribution), and social (demographic growth, political systems and practices, educational systems) similarities in Latin American countries indicate that they could address climate change with common (shared) methods.

14.1.2. Climate Variability and Change

There is ample evidence of climate variability at a wide range of time scales all over Latin America, from intraseasonal to long term. In many subregions of Latin America, this variability in climate normally is associated with phenomena that already produce impacts with important socioeconomic and environmental consequences that could be exacerbated by global warming and associated climate change. Signals that can be related to variability and/or change in climate conditions for Latin America have been identified in some of the analyses performed by researchers in the region, particularly for streamflow, precipitation, temperature, glacier oscillations, general circulation, and extreme events. Estimations of potential future climate conditions are based on climate change scenarios studies developed for some subregions of Latin America.

14.1.2.1. Past to Present

14.1.2.1.1. Glaciers, precipitation, and streamflow

Glaciers in Latin America have receded dramatically in the past decades, and many of them have disappeared completely (Williams and Ferrigno, 1998). In 18 glaciers in the Peruvian Andes, mass balances since 1968 and satellite images show a reduction of more than 20% of the glacial surface, corresponding to 11,300 million m^3 of ice (Morales-Arnao, 1969a,b; INAGGA-CONAM, 1999). Significant reductions also have occurred in southern Chile and Argentina (e.g., glacier Sarmiento) (Basso, 1997). Deglaciation may have contributed to observed negative trends in streamflows in that region (Morales-Arnao, 1999). For rivers in arid lands in northwest Peru and northeast and southeastern Brazil, significant negative trends also have been detected, but these variations seem to be related to human water management for irrigation purposes and increases in agricultural areas, rather than climate-induced changes (INRENA, 1994; Marengo, 1995; Marengo *et al.*, 1998).

Between 20°S and 40°S, precipitation around the Andes occurs mainly during the winter. Snow accumulates in the high parts of the cordillera and melts during the summer, becoming the main source of water for rivers in the region. Agricultural activities in central Chile and the Argentinean central western plains are maintained through irrigation. Therefore, it may be said with high confidence that fluctuations in winter precipitation have a strong socioeconomic impact in the region.

The precipitation record for Santiago, Chile, is highly correlated with snow depth in the cordillera. Recorded precipitation exhibited a decreasing trend from the late 19th century through the mid-1970s but has reverted since then. A similar trend has been detected in streamflow in the region (Minetti and Sierra, 1989; Carril *et al.*, 1997; Compagnucci and Vargas, 1998; Compagnucci *et al.*, 2000; Waylen *et al.*, 2000). In southern Chile and the Argentinean cordillera, a negative trend in precipitation and streamflow has been detected (Quintela *et al.*, 1993; Nuñez *et al.*, 1999).

In northwestern Mexico, there is a tendency for more winter precipitation, which has resulted in positive trends in river water levels. However, along with more intense winter precipitation, interannual climate variability has increased (Magaña and Conde, 2000). On the other hand, some parts of southern Mexico and Central America exhibit positive or negative rainfall trends, depending on the orientation of the catchment

(Aparicio, 1993; IPCC, 1996; Jáuregui, 1997; TAR WGI Chapter 3).

For Nicaragua, rainfall analysis for 1961–1995 showed negative trends in the north and northwest parts of the country. A systematic increment was detected on the Caribbean coast, and almost no variation was found along the central and the Pacific coastal regions (MARENA, 2000).

In Colombia, weak rainfall trends have been observed for the period 1955–1995, with no preferred sign at a regional level. For central Colombia, rainy seasons have been occurring earlier in recent years than 25 years ago (Mesa *et al.*, 1997). Trends in Colombian river streamflow are mixed, but the main river catchments such as the Cauca and Magdalena Rivers exhibit decreasing trends. Deforestation could account for such decreasing trends in river discharges (Poveda and Mesa, 1997).

For the Amazon region, Marengo *et al*. (2000) have identified multidecadal variations in rainfall in northern and southern portions of the basin, with opposite tendencies. Perhaps the most important finding is the presence of periods with relatively wetter or drier conditions that are more relevant than any unidirectional trends themselves. For instance, the period 1950–1976 was regionally wet in northern Amazonia, but since 1977 the region has been drier. This dryness does not seem to be related to regional deforestation (see Marengo *et al*., 1998; Marengo and Nobre, 2000; TAR WGI Chapter 3). Similarly, streamflow series in Amazonian rivers also exhibit multidecadal variations; they do not display significant unidirectional trends (Richey *et al*., 1989; Marengo, 1995).

In northeast Brazil, multidecadal variations in atmospheric circulation over the tropical Atlantic have been linked to similar time-scale variations in rainfall over the region (Hastenrath and Greischar, 1993; Nobre and Shukla, 1996; Wagner, 1996). On longer time scales, rainfall in northern northeast Brazil exhibits weak positive trends that are consistent with changes in decadal changes in circulation described in Wagner (1996).

Streamflow in the River Plate basin—particularly in the Negro, Paraguay, Paraná, and Uruguay Rivers—exhibits a negative trend from 1901 to 1970, which reverses after this period. Multidecadal variability also is observed in discharges (Garcia and Vargas, 1998; Genta *et al*., 1998; Robertson and Mechoso, 1998). Moreover, there are written reports of alternating floods and droughts periods during the 16th–18th centuries, indicating high natural variability (Prieto and Herrera, 1992).

In subtropical Argentina, Paraguay, and Brazil, precipitation exhibits a long-term change, with a sharp increase in the period 1956–1990 after a dry period along 1921–1955 (Castañeda and Barros, 1996). In the Pampa region, there is a positive trend in precipitation during the period 1890–1984. This increase in annual rainfalls was accompanied by a relative increase in precipitation during the spring and summer (Penalba and Vargas, 1996; Hoffman *et al*., 1997; Krepper and Sequeira, 1998). At high elevations in northwest Argentina, paleoclimatic records suggest an increase in precipitation in the past 200 years (Villalba *et al*., 1997). In the same region, as well as in Bolivia and southeast Peru, records show that the 17th-century climate was wetter and less variable (fewer floods and droughts), whereas the 18th century was highly unstable, with a large amplitude in the annual cycle and recurrent wet and dry periods (Prieto and Herrera, 1992).

Variations in precipitation in Latin America have a strong effect on runoff and streamflow, which also are affected by melting of glaciers and snow. Based on available information, there is evidence that these variations and their sign depend on the geographical subregion under consideration.

14.1.2.1.2. Temperature

Temperature in Latin America varies depending on the different subregions. For tropical Latin America, temperature depends on cloud cover and altitude; for other subregions, altitude, advection, and, at the southern cone, sea-surface temperature (SST) play more predominant roles. The following description is based on observed records; where possible, paleoclimatic information has been included to present a wider view.

Central America shows different signs for temperature trends, according to the specific area under analysis. For example, in Costa Rica, Alfaro (1993) identifies a positive trend in daily maximum temperature. Gómez and Fernández (1996) and OCCH (1999) have identified negative trends for large areas of Costa Rica and Honduras. MARENA’s (2000) analyses of time series for Nicaragua find only a small increase in mean temperature for Managua, which might be associated with growth in urbanization.

For northwestern South America, monthly mean air temperature records show a warming of 0.5–0.8°C for the last decade of the 20th century (Pabón, 1995a; Pabón *et al*., 1999; Quintana-Gomez, 1999). Colombia also presents increasing trends in the time series for the daily series of daily mean and minimum temperature for the past 30–40 years. Similar patterns have been observed in average monthly dew point and relative humidity (Mesa *et al.*, 1997; Pérez *et al*., 1998). Coastal cities from northern Peru presented increases in air temperature since 1940, where 16 El Niño events were reported (Jaimes, 1997; SENAMHI, 1999).

In several cities in southern and southeastern Brazil, studies on long-term tendencies for air temperature, from the beginning of the 20th century, have indicated warming tendencies (Sansigolo *et al.*, 1992). This could be attributable to urbanization effects or to systematic warming observed in the south Atlantic since the beginning of the 1950 s (Venegas *et al.*, 1996, 1998). In the Amazon region, Victoria *et al*. (1998) have detected a significant warming trend of +0.63°C per 100 years.

Data since the beginning of the 20th century do not show a clear tendency in mean temperature in the southern cone, but there is a decrease in the thermal range. Moreover, south of 50°S there are indications of a positive tendency (Hoffman *et al.*, 1997). However, when a shorter record is used for the analysis, Argentina and Chile show a large warming rate of 1.2–3.0°C per 100 years (Rosenblüth *et al*., 1997).

In south tropical Argentina, warming is observed only during the austral autumn season (Bejarán and Barros, 1998). The Argentina humid pampa, represented by Buenos Aires, presents a warming as a result of urban effects (Camilloni and Barros, 1997). Intensity and persistence of heat and cold waves present tendencies in which the sign depends on the region (Rusticucci and Vargas, 1998).

In extra-tropical west South America (Chile), surface air temperature has varied differently during the 20th century. South of approximately 45°S, temperatures have been increasing in stepwise fashion (Aceituno *et al*., 1993). In the area spanning about 35°S to 45°S, the most significant feature is a well-defined cooling of 1–2°C from the 1950s to the mid-1970s.

At decadal scales, multiple climate records throughout Latin America consistently exhibit a shift in the mean during the mid-1970s. This could be a climatic consequence of sudden changes in the climatology of the Pacific Ocean (Trenberth, 1990).

Using tree-ring and glacial evidence, summer temperatures in northern Patagonia show distinct periods of higher and lower temperatures during the past 1,000 years (Villalba, 1994; Villalba *et al*., 1997). For instance, there was a cold interval from AD 900 to 1070, followed by a warm period from AD 1080 to 1250 (coincident with the Medieval warm period). Warm climatic episodes similar to that observed during the 1980s may have occurred in the recent past under preindustrial CO_2 levels in northern Patagonia (Chile and Argentina) (Villalba *et al*., 1997).

Latin America, in general, shows important variations in temperature, some of which might be connected to change in climate. At the same time, these variations might depend on the origin and quality of the data as well as the record periods used for the studies.

14.1.2.1.3. Large-scale atmospheric circulation

Latin America's climate is influenced mainly by the northern Atlantic anticyclone and the migration of the inter-tropical convergence zone, which also affects large areas of tropical South America. The southern part of the continent is more affected by Atlantic and Pacific anticyclones, the thermic low pressure of northwestern Argentina, and mid-latitudes westerlie. All of these circulation features interact strongly with the complex topography of Latin America.

Analysis of ice cores in west Antarctica indicate that meridional atmospheric circulation intensity between middle and high latitudes has experienced substantial strength variability, increasing in the Little Ice Age (Kreutz *et al*., 1997; Leckenbush and Speth, 1999). At paleoclimatic time scales, analyses of fossilized pollen and lake sediments have shown more intense and frequent incursion of polar air from the Antarctic region 12,000–8,000 years before the present (BP) (Ledru *et al*., 1994).

In southern Brazil, there has been a tendency over the past 20 years for fewer wintertime cold fronts and polar outbreaks (Marengo and Rogers, 2000), which is somewhat consistent with reported interdecadal variations in the mean position and intensity of the south Atlantic anticyclone (Venegas *et al.*, 1998).

For mid-latitude South America, important changes in zonal circulation have been observed between 1899 and 1986, with wintertime circulation weaker for the period 1939–1949 and strong during 1967–1977—suggesting interdecadal changes. Over Paraguay, southern Brazil, Uruguay, and northeast Argentina, northeasterly circulation associated with the subtropical Atlantic anticyclone increases after 1954 (Hoffman *et al*., 1987; Minetti and Sierra, 1989; Cantañeda and Barros, 1993; Barros *et al*., 1999).

Instrumental records, sounding information, and satellite data show changes, fluctuations, and "sudden jumps" in some features of atmospheric circulation over Latin America and its adjacent oceans, in connection with detected changes in the global climate system.

14.1.2.1.4. Variability and impacts from El Niño and the Southern Oscillation

The extremes of the Southern Oscillation are partly responsible for large portions of climate variability at interannual scales in Latin America. Therefore, some of the variations in the foregoing elements could be associated with manifestations of climate variability, such as the El Niño phenomenon, which represents the low phase of the Southern Oscillation; the positive phase is referred to as La Niña. Atmospheric circulation patterns are more perturbed during El Niño than during La Niña years (Salles and Compagnucci, 1995, 1997).

In Mexico and parts of the Caribbean, the ENSO signal corresponds to more winter precipitation and less summer precipitation (Magaña and Quintanar, 1997). Some of the most severe droughts in Mexico in recent decades have occurred during ENSO summers (Magaña *et al.,* 1998). The signal of La Niña is almost opposite to the ENSO signal. In Central America, orographic effects play an important role in understanding regional ENSO effects in precipitation. During El Niño years, the Pacific side of Central America suffers an important reduction in precipitation, whereas some parts of the Caribbean side experience more rain than usual.

Over Colombia, ENSO events are associated with reductions in precipitation, river streamflows, and soil moisture, whereas

La Niña is associated with heavier precipitation and floods (Poveda and Mesa, 1997). There also is a very high positive correlation between the Southern Oscillation Index (SOI) and river discharge in Colombia. This relationship is stronger during the December–January period and weaker during April–May. The influence of ENSO is stronger at river stations located in western Colombia and weaker for stations located in eastern Colombia. Over the eastern part of the Andes, Ecuador, and northern Peru, large positive anomalies in precipitation typically are observed during the warm episode.

Dry anomalous conditions affect the Amazon region of Brazil northward to the Caribbean through the latter half of the year (Ropelewski and Halpert, 1987, 1989, 1996; Díaz and Kiladis, 1992). In northern Amazonia and northeast Brazil, deficient rainy seasons have been observed during ENSO years (Aceituno, 1988; Marengo, 1992; Uvo, 1998). Droughts that led to forest fires were detected during the very strong ENSO events of 1911–1912, 1925–1926, 1982–1983, and 1997–1998. Extreme droughts also occurred during these years in northeast Brazil. In contrast, the ENSO signal in southern Brazil is opposite to that in northeast Brazil and northern Amazonia, with positive and sometimes extremely large anomalies of rainfall during the rainy season of ENSO years, whereas drought can occur during the positive Southern Oscillation phase (Ropelewski and Halpert, 1989; Grimm *et al*., 1996, 2000).

Through northern and central Chile and at high altitudes of the Andes in Argentina, between 30°S and 40°S, most precipitation is recorded during the winter, with positive anomalies registered during early stages of the warm phase of ENSO. Because of the semi-arid conditions of this area, their economy is strongly affected (Quinn and Neal, 1982; Compagnucci, 1991; Ruttland and Fuenzalida, 1991; Canziani *et al*., 1997; Compagnucci and Vargas, 1998). At the same time, strong rainfall events occur in low altitudes of Chile, triggering debris flows during the winter such as those in Santiago and its surrounding areas in 1991–1993 (Garreaud and Ruttland, 1996) and 1997.

At high altitudes of the Andes, large amounts of snow are recorded consistently. Melting of this accumulated snow is the main cause of river runoff during the summer. In Chile and central-western Argentina, north of 40°S, streamflows were normal or above normal during El Niño years (Waylen and Caviedes, 1990; Compagnucci and Vargas, 1998; Compagnucci, 2000). On the other hand, during cold events (La Niña), negative anomalies of rainfall and snowfall are present—with opposite consequences, including below-normal summer streamflow. For this region, the likelihood of dry conditions during La Niña is higher than that of wet conditions during El Niño (Compagnucci and Vargas, 1998).

14.1.2.1.5. Extreme events

Cold and warm fronts, tropical cyclones, and severe convergence are some of the most frequent phenomena that produce floods, droughts, mud and snow slides, heat waves, frosts, and climate-related fires throughout Latin America. These extreme events produce direct and indirect impacts on productivity and affect the quality of life for Latin Americans. Ahazard (extreme climate phenomenon) becomes a disaster when it outstrips the ability of a country or region to cope.

There are subregions of Latin America where the occurrence of extreme events is very frequent. Central America and southern Mexico often experience the effect of tropical cyclones and associated heavy rain, flooding, and slides. For northwestern South America and northeastern Brazil, many of the extremes that occur are highly related to El Niño.

Sometimes these extreme events could be magnified to such a level (extreme of extremes) that the impact becomes a disaster. In Latin America, interaction with other complex phenomena, such as interannual or interdecadal oscillations, can contribute to create the appropriate conditions to produce a disastrous impact. Examples of these extraordinary extreme events include Hurricane Mitch in Central America, heavy rains in Venezuela, some of the most severe droughts in northeastern Brazil, and variations in ocean currents during El Niño for Peru and Ecuador.

Emanuel (1987, 1991) has suggested that warmer surface conditions and colder lower stratospheric temperatures would result in stronger hurricanes. Data for the eastern Pacific region indicate that the number of strong hurricanes in the region has been increasing since 1973 (Whitney and Hobgood, 1997). Such changes may represent a major environmental threat for countries such as Mexico (Jáuregui, 1995) and the Central American isthmus.

Some of the relatively weak cold surges may exhibit unusual intensity, causing frosts and low temperatures in coffee-growing areas of southeastern Brazil, resulting in heavy damage and losses in coffee production (Marengo *et al*., 1997). In the Mexican Altiplano, dry atmospheric conditions result in radiative cooling and frosts even during the summer (Morales and Magaña, 1998).

Even though it is still uncertain how global warming may affect the frequency and intensity of extreme events, extraordinary combinations of hydrological and climatic conditions historically have produced disasters in Latin America. Thus, in assessing vulnerability and adaptation mechanisms, it is necessary to consider the potential influence that global warming might have on extreme events.

14.1.2.2. Future: Climate Scenarios

Climate modeling has proven to be extremely useful in building projections for climate change and scenarios of future climate under different forcings. General circulation models have demonstrated their ability to simulate realistically the large-scale features of observed climate; hence, they are widely used to assess the impact that increased loading of the atmosphere with greenhouse and other gases might have on the climate system. Although there are differences among models with regard to the way they represent the climate system processes, all of them yield comparable results on a global basis. However, they have difficulty in reproducing regional climate patterns, and large discrepancies exist among models. In several regions of the world, distributions of surface variables such as temperature and rainfall often are influenced by the local effects of topography and other thermal contrasts, and the coarse spatial resolution of GCMs cannot resolve these effects. Consequently, large-scale GCM scenarios should not be used directly for impact studies, especially at the regional and local levels (von Storch, 1994); downscaling techniques are required (see TAR WGI Chapters 10 and 13).

At the large scale, rates of mean annual temperature changes in the Latin American region for the next century are projected to be 0.2–2°C (Carter and Hulme, 2000) under the low-emissions scenario (B1) produced as part of the IPCC *Special Report on Emission Scenarios* (SRES). The warming rate could range between 2 and 6°C for the higher emissions case (A2). Most GCMs produce similar projections for temperature changes on a global basis; projected changes in precipitation remain highly uncertain.

For impact studies, it is crucial to have a projection of concurrent changes of temperature and precipitation at the regional scale. Various scenarios of climate change for Latin America have been put forward on the basis of GCM projections under the IS92a scenario. Most of these regional scenarios are based on GCM experiments that are downscaled through statistical techniques. Derived climate change scenarios for Mexico suggest that climate in Mexico will be drier and warmer (Perez, 1997). Several hydrological regions in Mexico are highly vulnerable to decreased precipitation and higher temperatures (Mendoza *et al.*, 1997). A regional climate change scenario for central Argentina in response to CO_2 doubling under the IS92 scenario for the year 2050, also obtained through a statistical downscaling approach, shows a smaller increase in minimum temperature as compared to the maximum and larger increases for summer than for winter months, which generates enhanced temperature amplitudes (Solman and Nuñez, 1999). In addition, a decrease in precipitation is projected over the region, which is larger for summer (12%) than for winter months (5%). This result highlights an important consequence in the rainfall regime over the region: A large decrease in rainfall projected for the rainy season will seriously affect soil moisture, hence agricultural production in the region.

Several climate change scenarios for other parts of Latin America rely on linear interpolation of GCM output to estimate increases in surface temperature and precipitation (Mata, 1996; Carril *et al*., 1997; Hofstadter and Bidegain, 1997, Paz Rada *et al*., 1997; Centella *et al.*, 1998; MARENA, 2000). In the case of Costa Rica (MINAE-IMN, 2000), under the IS92a scenario for the year 2100, the results show a small increase in precipitation for the southeastern Caribbean region and an important decrease—close to 25%—in the northwestern Pacific region. This latter region already experiences water problems as a result of El Niño and an increasing demand from infrastructure for tourism and irrigation. Under the same climate scenario, mean temperature in Costa Rica is expected to rise by more than 3°C by 2100, and tendencies in actual climate series (1957–1997) show already an increase of 0.4°C every 10 years for the more continental Central Valley areas. This last estimation may reflect signals other than the one related to climate change.

Results from climate scenarios for Nicaragua imply an additional pressure on productivity sectors and human activities. Under the IS92a emissions scenario, mean temperature for the Pacific watershed would be expected to rise, ranging from 0.9 for the year 2010 to 3.7°C for the year 2100, and precipitation would

Table 14-1*: Estimated changes projected under IS92 scenario for some countries within Latin America region.*

Region	**Temperature**	**Precipitation**
Mexico	increase	decrease
Costa Rica		
– Pacific sector	+3°C	-25%
– Southeast Caribbean sector		small increase
Nicaragua		
– Pacific sector	+3.7°C	-36.6%
– Caribbean sector	+3.3°C	-35.7%
Brazil		
– Central and south central sector	+4°C	+10 to +15% for autumn reductions for summer
Central Argentina	summer: +1.57°C (+1.08–2.21°C) winter: +1.33°C (+1.12–1.57°C)	summer: -12% winter: -5%

decrease by 8.4% for the year 2010 and 36.6% for the year 2100. For the Caribbean watershed, mean temperature would increase, ranging from 0.8°C for the year 2010 to 3.3°C for the year 2100, and precipitation would decrease in a range between 8.2% for the year 2010 and 35.7% for the year 2100 (MARENA, 2000).

Potential effects of climate change in Brazil suggest changes of 4–4.5°C in surface temperature as a result of increased CO_2 concentrations (de Siqueira *et al*., 1994, 1999). Central and south-central Brazil may experience increases of 10–15% in autumn rainfall; reductions could appear during December, with high risk of drought during summer, affecting crops (see Table 14-1).

Analysis of climate variations during the instrumental period and evidence suggested by paleoclimatic and other proxy climate information suggests that climate variations and change have been found in several regions in Latin America. Most climate records cover the past century; at this time scale, there have been indications of multidecadal and interannual variability, some linked to extremes of the Southern Oscillation. The lack of continuous and long-term records from the past does not allow one to identify climate patterns with a high degree of confidence to determine whether these climates were similar to or much different from that of present times—particularly with respect to the frequency and intensity of extreme events such as drought, floods, freezes, heat waves, and especially hurricanes and tropical storms. However, multidecadal variations have been identified in rainfall and streamflow records in the region, although no clear unidirectional trend indicators of climate change have been identified.

14.1.3. Socioeconomic and Trade Agreements Issues

14.1.3.1. Socioeconomic Issues

Latin America has one of the greatest disparities in income distribution in the world. From the social and environmental point of view, the region clearly is vulnerable to the effects of natural disasters. Inappropriate land use, for agriculture and human settlements, in watersheds causes serious damages during the occurrence of extraordinary climate extreme events, such as Hurricanes George and Mitch in Central America and intense rain events in Venezuela and Argentina. CEPAL (1999a,b,c,d,e) estimated losses from Hurricane Mitch (see Table 14-2). Losses in Honduras and Nicaragua were 70 and 45% of GNP, respectively, affecting the development and economic growth of both countries. There is strong evidence that the effects of natural disasters contribute to rising poverty and inequality in many regions of Latin America.

Table 14-2: *Estimated losses from Hurricane Mitch.*

Country	Losses (US$ million)	Percentage of GNP
Costa Rica	92	1.0
El Salvador	388	6.1
Guatemala	748	1.5
Honduras	4,000	70.0
Nicaragua	988	45.0

The year 1998 was one of the most problematic periods in recent times for Latin America and the Caribbean. The side effects of the international financial crisis that originated in Asia in the middle of 1997 limited the possibilities for the region to obtain external aid. In addition, many adverse climatic events worsened the socioeconomic conditions. The Latin American region hosts a myriad of socioeconomic conditions. Countries with a high level of development coexist with least-developed countries. Macro-economic figures indicate a moderately constant degree of growth in the region, even though more than 200 million people in Latin America are poor (CEPAL, 1998).

The Human Development Report for 1998 (UNDP, 1998), in its section on consumption patterns, notes that the overwhelming majority of people who die each year from pollution are poor people in developing countries. Large cities in Latin America such as Mexico City already have a serious problem with air pollution. The report also identifies several issues that affect most of Latin America which may be increased by global warming, including desertification, floods and storms, and harvest. Poor people are less resilient to these problems.

The World Bank (1997) analyzed the 1982–1983 El Niño event and, with a great degree of certainty, considered it to be the most intense in the 20th century. Losses from droughts, floods, and hurricanes were estimated at US$14 billion. Of these, US$2 billion were lost in the western coast of South America, half in Peru—mainly losses from fishing revenue and destruction of infrastructure. Social losses also were very high. Reconstruction and development of related activities in Peru depleted resources and resulted in losses of 6% in GNP. Damages in Peru in 1997–1998 were on the order of US$1 billion (of which 55% was transportation infrastructure, 15% agriculture, 14% energy, and 9% education), and more than 400 relief projects had to be implemented, requiring emergency attention in 14 of the 24 departments of Peru. Some positive effects resulted, such as increases in pastures (200,000 ha) and reforestation of 100,000 ha.

One sector that might be affected by climate change, based on previous experiences during the ENSO period, is fisheries. Fish capture was reduced by 53% during the 1998 ENSO event (IMARPE, 1998). However, adaptation measures such as changing the species captured and price increases reduced the losses to 40%. Some adaptation options, such as switching from anchovy to tuna, can significantly reduce losses from seawater warming (Arntz and Fahrbach, 1996; IMARPE,1998). Adaptation to flooding conditions may reduce damage from extreme floods. One way to address water-shortage areas is to store excess water; for example, a lake was created in north Peru in 1998 (IMARPE, 1998).

Insurance is an important financial aspect that may be impacted by climate change. A joint World Meteorological Organization/Inter-American Development Bank (WMO/IDB) meeting—with participation by scientists, bankers, and insurers—recognized the importance of climate change in insurance policy and of the need for increased cooperation (WMO, 1994), but few concrete actions materialized, mainly because insurers feel that larger risks should be compensated with higher insurance premiums.

14.1.3.2. Trade Agreements

Several trade agreements exist in the region and have important effects on the economy and, indirectly, on the environment of the region. The most important of these agreements are listed in Table 14-3. Regional intergovernmental agreements could be an important mechanism for adaptation to climate change in Latin America. Agreements such as the one developed for conservation of water, the environment, and natural disaster management in the Central American isthmus (Central American Integration System—SICA) could be interpreted as a way to coordinate sectorial adaptation to different climatic conditions. During the South American presidential meeting in August 2000, leaders attempted to consolidate efforts for the region's political and economic integration, with emphasis on free trade. Because natural disasters cause a decline in productive capacity and increase demand for strong public and private investment in reconstruction, imports are likely to increase and exports are likely to fall, leading to a trade deficit. Disasters such as floods, droughts, and hurricanes also may lead to a significant increase in food product prices if production and distribution are disrupted (IDB, 2000).

There also have been other agreements on the technological and scientific agenda, such as initiatives to foster research on global and climate change and environmental issues. The Inter-American Institute for Global Change (IAI) supports research initiatives to document climate variability and change characteristics and their societal impacts in the Latin American and Caribbean region.

14.1.4. Environmental Legislation

Ratification of international and regional conventions and agreements brings the responsibilities and commitments associated with them into the text of national legislation. As a consequence, ratification of the recommendations of the United Nations Conference on Environment and Development (UNCED, 1992) by Latin American governments has initiated a path for preventive actions for natural hazards, as well as other recommendations included in Agenda 21 to be incorporated into national legislation. The same is true for the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention on Biodiversity, and the United Nations Convention to Combat Desertification and Drought.

***Table 14-3**: Important trade agreements in Latin America region.*

Agreement	Participating Countries	Notes
Asociación Latinoamericana de Libre Comercio (ALADI)	Spanish speaking countries of the region	Not a particularly active agreement.
Pacto Andino (Andean Pact)	Bolivia, Colombia, Ecuador, Peru, and Venezuela	Tends to eliminate duties in a gradual way. Has incorporated an environment unit and places increasing attention on environmental issues.
Mercosur	Argentina, Brazil, Paraguay, and Uruguay	Bolivia and Chile are associate members. Tends to eliminate duties in a gradual way. Future common currency under consideration.
Central American Common Market	Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua	One of the oldest trade agreements. Plans to convert to a free-trade zone.
North America Free Trade Agreement (NAFTA)	Mexico, plus Canada and USA	Very successful for expanding trade. Strict environmental considerations. Plans call for expansion to all Latin American countries.
Bilateral agreements	Several pairs of countries or groups	Environmental considerations increasingly important, especially in agreements with the European Union.

This also has been the case with the adoption of the Vienna Convention on the Protection of the Stratospheric Ozone Layer and its Montreal Protocol. Similar steps will be needed should the Kyoto Protocol be ratified. The UNFCCC, particularly Articles 2 and 4, calls for action vis-à-vis climate variations, and the Kyoto Protocol opens avenues for mitigation of greenhouse gas (GHG) emissions; through Article 12, on Clean Development Mechanisms, the UNFCCC makes provision for assistance and transfer of technology from Annex I to non-Annex I Parties.

There also are a substantial number of regional agreements and a huge body of laws, rules, and regulations to ensure systematic and coordinated actions for protecting the environment, including flora and fauna and coastal and inland wetlands, as well as to promote sustainable development (PNUMA, 1991; Bertucci *et al.*, 1996; Solano, 1997). Most Latin American governments have a comprehensive environmental legal framework with relevant laws, rules, and procedures for specific resources and activities (e.g., water, forestry and mineral resources, marine resources and coastal areas, hunting and fishing, and tourism, as well as specific products and pesticides and pollution) (Sebastiani *et al.*, 1991, 1996a,b). Latin American governments also have developed national and regional environmental plans and strategies, as well as other sectoral or special programs. Although implementation in some countries is far from satisfactory, it also is very common to find legislation that regulates the use of natural resources and makes provision to punish noncompliance (Solano, 1997). In a large number of countries in the region, recent legal developments on environmental management include mandatory environmental impact assessment (EIA) studies. All Latin American countries are expected to adopt this policy. With regard to the climate component, the main shortcomings highlighted in the report to the IPCC Bureau on Systematic Observations are lack of sufficiently dense terrestrial and marine observing systems; lack of systematic observations on specific biological variables and socioeconomic impacts, as well as GHGs and aerosols; and consolidation of land surface observations (hydrology, ecosystems, and land use) (WMO, 1998). This means that, generally speaking, there are limitations that affect the value and reliability of EIAs in some areas of the region.

In line with United Nations Resolution A/52/629—which calls for cooperation to incorporate sustainable development programs at national, regional and global levels—countries in Latin America are engaged in fulfilling the objectives of such development programs. In this respect, policymakers and decisionmakers should be made aware of the role played by climate variation issues in such development strategies. The large majority of countries follow the recommendations made by the United Nations Commission for Sustainable Development (UNCSD), and the Economic Commission for Latin America and the Caribbean (ECLAC) is assisting them in integrating relevant disciplines and sectors, particularly for incorporating natural hazard response strategies in sustainable development policies. However, more work still is needed, as a result of the aforementioned shortcomings in the operation of observing and monitoring systems as well as the need for capacity-building on issues related to sustainable development and their well-known linkages with climate issues. Such action becomes relevant to efforts for mitigating environmental hazards and acting in line with the planning of the Pan-American Climate Information and Applications System (PACIS), as suggested by the Summit of the Americas in Santiago, Chile, in 1998.

As environmental concerns become more pressing, they are climbing higher on the international political agenda. Globalization in its many guises poses an enormous challenge for traditional governance structures. While nations—particularly developing nations—are losing ground in globalization, other actors are moving to the forefront, particularly international corporations and nongovernmental organizations (NGOs). Therefore, governments should not only take into account this new spectrum of participants in future environmental legislation but, above all, give them specific and urgently required roles in defense of the environment. New information and communication technologies are facilitating international networking, and activist groups, businesses, and international institutions are forging innovative partnerships.

14.1.5. Summary of Main Findings from the IPCC Special Report on Regional Impacts of Climate Change

Glaciers in the high Andes and three major ice fields in southern South America represent the cryosphere in Latin America. Warming in high mountain regions could lead to disappearance of significant snow and ice surfaces. In addition, changes in atmospheric circulation resulting from the ENSO phenomenon and climate change could modify snowfall rates—with a direct effect on the seasonal renewal of water supply—and surface and underground runoff in piedmont areas. This could affect mountain sports and tourist activities, which represent an important source of income in some economies. Glaciers are melting at an accelerated rate in the Venezuelan (Schubert, 1992; Hastenrath and Ames, 1995) and Peruvian Andes.

In the humid tropics, extreme precipitation events would increase the number of reservoirs silting up well before their design lives have been reached. Other areas affected by the impact of climate change on water resources could be those that rely on freshwater ecosystems (i.e., lakes and inland wetlands and their biota), including commercial and subsistence fisheries.

According to climate change projections, approximately 70% of the current temperate forest in Mexico could be affected by climate change (Villers, 1995). Other vulnerability studies (Gay-García and Ruiz Suarez, 1996)—carried out on the basis of Canadian Climate Centre (CCC)-J1 (Boer *et al*., 1992; McFarlane *et al*., 1992; Boer, 1993) and Geophysical Fluid Dynamics Laboratory (GFDL)-A3 (Wetherald and Manabe, 1988) GCMs—suggest that 10% of all vegetation types in northern Mexico’s ecosystems—including forests and shrublands of southern Chihuahua, eastern Coahuila, northern Zacatecas, and San Luis Potosì—would be affected by drier and warmer conditions, resulting in expansion of dry and very dry tropical forests and xerophytic shrublands.

Studies of vulnerability to sea-level rise (Perdomo *et al.*, 1996) have suggested that countries such as Venezuela and Uruguay could suffer adverse impacts, leading to losses of coastal land and biodiversity, saltwater intrusion, and infrastructure damage. Impacts likely would be multiple and complex, with major economic implications. In Central America, impacts associated with sea-level rise would have their greatest effects on infrastructure, agriculture, and natural resources along the coastline, with immediate effects on socioeconomic conditions in the isthmus countries. Sea-level rise would exacerbate the processes of coastal erosion and salinization of aquifers and increase flooding risks and the impacts of severe storms along the coastline (Campos *et al*., 1997). Flooding associated with sea-level rise is one of the main impacts in lowland areas such as the Amazon, Orinoco, and Parana River deltas and the mouth of other rivers, such as the Magdalena in Colombia. The report also identified the Rio de La Plata estuary as an area where saltwater intrusion could create problems in the freshwater supply.

In Latin America's extremely arid deserts (<100 mm annual precipitation)—the Chihuahuan, Sonoran, Peruvian, Atacama, Monte, and Patagonia—the impacts of climate change are not expected to be severe (Canziani *et al.*, 1998), because these systems already are adapted to wide fluctuations in rainfall. Therefore, hyper-arid lands are not as susceptible as drylands to climate change (Middleton and Thomas, 1997).

Studies developed in Costa Rica and Nicaragua (Halpin *et al*., 1995) observed that shifts may occur in climatic zones that are associated with particular vegetation types in these countries. Global warming would have its greatest impacts on the cold temperate forest of southern Chile and Argentina, especially those neighboring xerophytic ecosystem types.

Projected changes in climate could increase the impacts of already serious chronic malnutrition and diseases affecting a large sector of the Latin American population. The geographical distribution of vector-borne diseases (e.g., malaria) would spread to higher elevations.

14.2. Key Regional Concerns

Studies developed after the *Special Report on Regional Impacts of Climate Change* (RICC) add new findings on the potential impact of climate change on different sectors in Latin America. Many of these new studies evolved from those mentioned in RICC, indicating that a process is in place in Latin America to reduce uncertainties associated with climate change.

14.2.1. Natural Ecosystems

Climate variations produce a variety of impacts on natural ecosystems (see Sections 5.4 to 5.9). Latin America possesses a large quantity of ecosystems, ranging from Amazonian tropical rainforest to cold Andean systems (Paramos). It also hosts remarkable rangelands, shrublands, deserts, savannas, grasslands, coastal wetlands (mainly along the Caribbean and Atlantic coastlines), and inland freshwater wetlands such as Pantanal and Iberá. Natural ecosystems in Latin America can be expected to suffer a variety of impacts from climate change. Latin American humid tropical forests represent an important group of ecosystems for which a great deal of information is offered (e.g., Canziani *et al*., 1998).

14.2.1.1. Humid Tropical Forests

Conversion of large areas of tropical forest to pasture could reduce water cycling and precipitation in the region, in addition to its global role as a contribution to global warming. Pasture has much less leaf area than forest (McWilliam *et al*., 1993). Because evapotranspiration is proportional to leaf area, water recycled through forest is much greater than that recycled through pasture—especially in the dry season, when pasture is dry but forest remains evergreen (Roberts *et al.*, 1996). This is aggravated by the much higher runoff under pasture, with measured increases of more than 1,000% in small (10 m^2) plots (Fearnside, 1989). Pasture grasses can partially compensate for reduced evapotranspiration by increasing their efficiency of water use when soil moisture is low, whereas forest trees maintain constant efficiency (McWilliam *et al.*, 1993). Soil under pasture quickly becomes highly compacted, inhibiting infiltration of rainwater into the soil (Schubart *et al*., 1976). Rain falling on compacted soil runs off quickly, becoming unavailable for later release to the atmosphere through transpiration. The shallower root system of pasture, compared to that of forest, prevents pasture from transpiring during periods of drought (Nepstad *et al*., 1994, 1999). Precipitation decreases therefore are greatest at the time of year when rain is most needed.

If the extent of deforestation were to expand to substantially larger areas, we have high confidence that reduced evapotranspiration will lead to less rainfall during dry periods in Amazonia and medium confidence that rainfall will be reduced in the center-west, center-south, and south regions of Brazil (Lean *et al.*, 1996). Although the annual rainfall total in Amazonia would decrease by only 7% from conversion to pasture, based on simulations with the Hadley Centre model, in August (dry season) the average rainfall would decrease from 2.2 mm day^{-1} with forest to 1.5 mm day^{-1} with pasture—a 32% decrease (Lean *et al*., 1996). Simulations of conversions of Amazonian forest to pasture, using the Météo-France EMERAUDE GCM, indicate reduced volumetric soil moisture in the "arc of deforestation" where clearing activity is concentrated along the southern boundary of the Amazon forest. Rainfall reduction in southern Brazil is greatest for the January–March period (Manzi and Planton, 1996).

Greater dependence of Amazonian rainfall on water derived from evapotranspiration in the dry season means that conversion to pasture would cause this period to become longer and more severe—a change that could have harsh repercussions on the forest even if total annual precipitation were to remain unchanged (Fearnside, 1995). In patches of forest isolated by cattle pasture, trees on the edges of forest patches die at a much greater rate than do those in continuous forest (Laurance *et al*., 1997, 1998; Laurance, 1998). Because many trees die while they are still standing, rather than being toppled by wind, dry conditions (particularly in the air) near reserve edges are a likely explanation for mortality. Soil water may partially counterbalance the effect of drier air; as trees die, soil water in the gaps they leave normally increases because the roots that would have removed water from the soil are gone. Increasing vines and decreasing forest biomass are strongly associated near forest edges, probably as a consequence of a positive feedback relationship between these factors (Laurance *et al*., 2000). Drier microclimatic conditions have been found at forest edges (Kapos, 1989). Increased water stress—as indicated by altered ^{13}C in plant leaves—extends 60 m into the forest from an edge (Kapos *et al*., 1993). Tree mortality increases significantly up to 100 m from the forest edge (Laurance *et al*., 1998). Considering the length of forest edges measured by Skole and Tucker (1993) for the Brazilian Amazon in 1988, a 100-m disturbance buffer to these edges would represent a disturbed area in 1988 of 3.4 x 10^6 ha, or 15% of the area cleared by that year. Forest edges, which affect an increasingly large portion of the forest with the advance of deforestation, would be especially susceptible to the effects of reduced rainfall.

Greater severity of droughts reinforced by deforestation effects could lead to erosion of the remainder of the forest once a substantial portion of the region had been converted to pasture. The greatest effects are likely to occur during occasional complex phenomena such as El Niño (Tian *et al*., 1998; Nepstad *et al*., 1999). Precipitation in Amazonia is characterized by tremendous variability from 1 year to the next, even in the absence of massive deforestation (e.g., Fearnside, 1984; Walker *et al*., 1995). If the forest's contribution to dry-season rainfall were to decrease, the result would be to increase the probability of droughts that are more severe than those experienced in the centuries or millennia over which the present forest became established. Occasional severe droughts would kill many trees of susceptible species. The result would be replacement of tropical moist forest with more drought-tolerant forms of scrubby, open vegetation resembling the *cerrado* (scrub savanna) of central Brazil (Shukla *et al*., 1990)

Until recently, burning in Amazonia has been almost entirely restricted to areas where trees have been felled and allowed to dry before being set alight. Fire normally stops burning when it reaches the edge of a clearing rather than continuing into unfelled forest. Archaeological evidence suggests that catastrophic fires have occurred in Amazonia during major El Niño events four times over the past 2,000 years: 1,500, 1,000, 700, and 400 BP (Meggers, 1994). Human action could now turn less intensive El Niño events, which are much more frequent than major ones, into catastrophes. Increased fire initiation foci, together with increased forest flammability from logging, already have resulted in substantial incursions of fires into standing forest in eastern and southern Amazonia during dry years (Uhl and Buschbacher, 1985; Uhl and Kauffman, 1990; Cochrane and Schulze, 1999; Cochrane *et al*., 1999; Nepstad *et al*., 1999). The 1998–1999 fires in Roraima, in the far northern portion of Brazil, reflect the vulnerability of standing forests in Amazonia during El Niño events now that settlement areas in the forest provide permanent opportunities for fire initiation (Barbosa and Fearnside, 1999).

Increases in the amount of biomass burning could affect nutrient cycling in Amazonian forest ecosystems (medium confidence) (Fearnside, 1995). Droughts lead to increases in the area and completeness of burning in clearings in Amazonia, contributing to smoke and dust that function as sources of wind-borne nutrients to the surrounding forest (Talbot *et al*., 1990). Climatic change also could increase nutrient supply via long-range transport of dust. African dust transported across the Atlantic Ocean by winds may be supplying significant amounts of phosphorus and calcium to Amazonia (Swap *et al*., 1992). Amazonian soils are very poor in these elements. Soil nutrients are among the factors that limit growth, recruitment, and mortality of trees (Laurance *et al*., 1998; Sollins, 1998). Smoke and ash particles from burning in savannas, possibly including those in Africa, also contribute nutrients (Talbot *et al*., 1990). The extent to which these nutrient sources could increase the growth of Amazonian forests is not known. Increases undoubtedly differ by tree species, thereby altering forest composition. Burning is affected by climate, as well as by the size and behavior of the human population. Factors that influence the growth of intact forests in Amazonia are particularly important because of the large amounts of carbon that could be released to or removed from the atmosphere if the balance between forest growth and decay is altered.

CO_2 enrichment is believed to contribute to observed imbalances between CO_2 uptake and release by forest biomass in Amazonia; forest recovery from past disturbances also may contribute to these imbalances. Eddy correlation measurements (studies of gas movements in air flows inside and immediately above the forest) at one site in Rondônia indicated an uptake of 1.0 ± 0.2 t C ha^{-1} yr^{-1} (Grace *et al*., 1995). A similar eddy correlation study near Manaus found uptake of 5.9 t C ha^{-1} yr^{-1} (Malhi *et al*., 1999). An estimate based on reviewing existing measurements of tree growth and mortality in permanent plots found mean uptake of 0.62 ± 0.37 t C ha^{-1} yr^{-1} (Phillips *et al*., 1998). On the other hand, at the Biological Dynamics of Forest Fragments site near Manaus (the largest and longest running study included in the forest growth measurement data set), no uptake or loss was found in 36 1-ha control plots located >100 m from a forest edge (Laurance *et al*., 1997). The Rondônia and Manaus eddy correlation studies and the basin-wide review of tree growth indicate uptakes of 0.63, 3.66, and 0.38 x 10^9 t C, respectively, when extrapolated on the basis of consistent definitions of forest that indicate a total area of forest in the Amazon Basin of 620.5 x 10^6 ha (Fearnside, 2000). A process-based model of undisturbed ecosystems in the Amazon Basin, including savannas and forests (not necessarily defined as above), indicates wide interannual variations in net carbon flux from vegetation and soil, ranging from emissions of 0.2 x 10^9 t C in El Niño years to a sink of as much as 0.7 x 10^9 t C in other years; mean annual flux simulated over the 1980–1994 period gives an uptake of 0.2 x 10^9 t C (Tian *et al*., 1998). If the frequency of El Niño events increases as a consequence of global warming (Timmermann *et al*., 1999), these forests may release some of their large carbon stocks to the atmosphere. The future course of accumulation of CO_2 in the atmosphere—and consequently the time when concentrations would reach "dangerous" levels—depends heavily on continued uptake of carbon by the biosphere, including an important contribution from Amazonian forests. Climate effects contribute to making the sink in Amazonian forests unreliable as a brake on atmospheric carbon accumulation.

Although temperature changes from global warming are expected to be modest in the tropics as compared to temperate regions, it is important to realize that each degree of temperature alteration in a tropical environment may be "perceived" by forest species there as a greater change than would be the case for the same temperature shift in a temperate forest (Janzen, 1967). The direct effects of global warming on ecosystems at relatively low latitudes, if not at the equator itself, therefore may be greater than the small predicted temperature alterations at these sites might lead one to believe. In addition, direct effects of global warming through temperature change are likely to be less pronounced than effects that temperature can have through its influence on other climatic parameters, such as rainfall (Fearnside, 1995).

GCMs indicate a range of results for the effect of global warming on precipitation in Amazonia. Drying generally is expected; some models indicating greater drying than others. The Hadley Centre's HadCM2 model indicates especially dry climate over Amazonia. Process-based ecosystem models that use this simulated climate show large declines in net primary productivity (NPP) and release of carbon as a result of Amazonian forest dieback (Friend *et al.*, 1997). The varied GCM results suggest the need for a range of climate scenarios as inputs to ecosystem simulations (Bolin *et al*., 2000). It should be noted that available scenarios (e.g., Nakicenovic *et al*., 2000) represent the change in climate resulting from altered composition of the atmosphere only, not the additional impacts of regional land-use changes such as replacement of Amazonian forest by pasture.

Globally, models show that a doubling of GHGs may lead to a 10–15% expansion of the area that is suitable for tropical forests as equilibrium vegetation types (Solomon *et al*., 1993). For tropical rainforest, the suitable area would expand 7–40%, depending on the GCM employed in estimating the future distribution of climatic zones. The GCM studies used by Solomon *et al*. (1993) assess the effects of doubled GHGs (i.e., CO_2-equivalence), through the direct effects of temperature and through temperature-driven alteration of precipitation regimes (but not rainfall changes provoked by deforestation). These results are indicators of *potential* for forest expansion and are not intended to reflect expected landscapes in the future; they do not include the influence of human populations in converting to other uses land that is climatically suitable for tropical forests.

One model that includes climate-induced and human changes to the year 2050 points to decreases in forest areas by about 5% in Latin America (Zuidema *et al*., 1994). The deforestation estimates used in these calculations are based on the areas needed to satisfy expected demands for agricultural products. In the case of Brazil, deforestation is likely to exceed these forecasts because much of the forest clearing stems from motivations other than consumption of agricultural products (Hecht *et al*., 1988; Reis and Margulis, 1991; Hecht, 1993; Fearnside, 1997). In any case, the combination of forces driving deforestation makes it unlikely that tropical forests will be permitted to expand to occupy the increased areas that are made climatically suitable for them by global warming. Land-use change interacts with climate through positive feedback processes that accelerate the loss of Brazil's Amazonian forests.

14.2.1.2. Dry Forests

Seasonally dry tropical forests have wide global distribution and coverage. Nearly 42% of tropical forests around the world are seasonally dry plant communities (Murphy and Lugo, 1986). Ancient Mesoamerican cultures developed in these regions. Domestication of animals and plants (e.g., maize, beans, sweet potato) has occurred mainly in dry forests (Challenger, 1998). Degradation of these seasonal forests is similar to or even greater than that of tropical rain forests, and only a small fraction remains intact (Janzen, 1988; Gentry, 1995; Murphy and Lugo, 1995). Janzen (1988) argues that because only a small proportion of the original distribution of dry forest remains intact in Mesoamerica, neotropical seasonally dry forests should be considered severely threatened. The estimated deforestation rate for Mexico, for the 1973–1989 period, is 1.4% yr^{-1}, which is equivalent to loss of 17.9 km^2 yr^{-1} (Trejo and Dirzo, 2000).

Costa Rican and Nicaraguan forests will be more severely affected by changes in precipitation than by changes in the annual mean temperature (see Section 14.1.5). In Venezuela, 40–50 Mha of moist forest will shift to dry or very dry forest under climate change scenarios (Mata, 1996). Between 44 and 51% of the total covered area of the Mexican deciduous tropical forest will be affected (Villers-Ruiz and Trejo-Vázquez, 1997).

Burning in the Cerrado shrubland that borders Amazonian forest to the south has increased in frequency in recent decades. This appears to create an unfavorable nutrient balance for the entire Amazonian ecosystem (Coutinho, 1990).

14.2.1.3. Savannas, Grasslands, and Deserts

Latin American dryland ecosystems are seriously threatened by desertification processes that have negative social, economic, ecological, cultural, and political consequences (Benedetti, 1997;

***Table 14-4**: Estimated land use, drylands, desertification (modified from Dregne and Chou, 1992).*

Country	Irrigated Area (10^3 ha)	% Desertified	Rainfed Cropland Area (10^3 ha)	% Desertified	Rangeland Area (10^3 ha)	% Desertified	Hyperland Area (10^3 ha)	Total Drylands (10^3 ha)
Argentina	1,680	31	12,068	10	178,878	70	0	192,626
Bolivia	160	19	1,458	31	31,069	85	0	32,687
Brazil	2,300	11	3,904	69	74,558	90	0	80,762
Chile	1,257	8	1,281	47	20,976	80	11,740	35,254
Colombia	324	3	322	40	9,376	85	0	10,022
Cuba	390	1	35	14	10	90	0	435
Ecuador	540	7	400	62	7,986	90	0	8,926
El Salvador	110	5	10	10	15	93	0	135
Guatemala	75	8	88	11	719	89	0	882
Mexico	4,890	36	10,005	54	113,142	90	1,738	149,775
Paraguay	65	8	42	5	16,326	31	0	16,433
Peru	1,210	34	1,027	78	40,121	85	8,097	50,455
Venezuela	324	12	345	29	9,728	70	0	10,397

Anaya, 1998). Desertification is defined as land degradation in arid, semi-arid, and dry subhumid areas resulting from various factors, including climactic variations and human activities (conclusion from Earth Summit of Rio de Janeiro in 1992—UNCED, 1992). Evaluation of desertification around the world is complex because there is no unique measure of aridity. For example, using Thornthwaite's aridity index, 75% of Mexico is considered arid land (Thornthwaite, 1948). However, Garcia (1988) states that the arid region constitutes just more than 50% of Mexico. Large variability in the temporal and spatial distribution of precipitation complicates determination of arid and semi-arid region extension and consequently analysis of land degradation (Balling, 1994; Williams and Balling, 1996; Hernández and García, 1997).

At a global scale, the main desertification processes are degradation of vegetation, water and wind erosion, and salinization and waterlogging (Dregne and Chou, 1992). Major land-use activities in arid regions, such as irrigation and rainfed agriculture and livestock on rangelands, also are common factors in land degradation in various Latin American countries (see Table 14-4). In irrigated lands, salinization and waterlogging mainly cause the desertification. In rainfed cropland, the dominant processes for desertification are water and wind erosion; in this case, the percentage of the affected areas ranges from 10% for Argentina and El Salvador to 78% for Peru. Rangeland desertification is caused by overgrazing that results in vegetation degradation, as well as deforestation of woody species for fodder, fuel, charcoal production, and construction materials. Rangelands correspond to the major surface of drylands, where the percentage of desertified areas reach the highest levels (70–90%) compared to other land uses. On the other hand, according to the Global Assessment of Human-Induced Soil Degradation (GLASOD) survey (Middleton and Thomas, 1997), deforestation and removal of natural vegetation cover is the primary cause of soil degradation in South America, affecting 41.7% of the 79.1 Mha of drylands. The most affected regions are in northeast Brazil, along the Caribbean coasts of Venezuela and Colombia, and in northern Argentina (semi-arid Chacoan). Secondary causes of soil degradation are overgrazing (26.2%) and agricultural activities (11.6%) (<100 mm annual precipitation).

According Greco *et al.* (1994), precipitation changes projected under various climate change scenarios are unlikely to produce major ecosystem changes in this region. However, normal variations in rainfall patterns that are characteristic of this region may induce cyclic changes in vegetation physiognomy. These variations probably are more important than the total amount of precipitation. Very humid years may affect the vegetation of the region. For example, in San Luis Potosi, Mexico, in 1955, heavy rainfall from a large number of hurricanes caused the "mezquital" (*Prosopis*) shrub to disappear as a consequence of extremely wet soils, and the region became a grassland (Medellín-Leal and Gómez-González, 1979).

In the same way, the presence of El Niño in 1997–1998 in coastal arid zones of northern Peru generated drastic temporal changes in dry forest ecosystems (Torres Guevara, 1992). That area, where the historical average of annual precipitation is only 20–150 mm, received 1,000–3,000 mm of rainfall between December 1997 and May 1998. This precipitation had positive and negative effects in the region: NPPincreased in all vegetation communities (Torres Guevara, 1992), reactivating rainfed agriculture activities. However, there was an outbreak of insect pests that reduced NPP.

14.2.1.4. Temperate Forests and Mountain and Polar Ecosystems

Studies carried out in Latin America on the potential impact of climate change in mountain ecosystems report an increase in mean temperature followed by a gradual reduction of glaciers in the high mountains (Flórez, 1992). As Flórez (1992) has reported, in Colombia there will be an ascent of the altitudinal limits of forest and agriculture, reducing the paramo life zone and possibly causing disappearance of current flora and fauna. The limits of the Andean and sub-Andean life zones also would ascend, as would the upper limit of the lowland tropical forest zone (Pabón, 1995b; van der Hammen, 1997). In the same way, studies in Costa Rica suggest the same effect on the tropical montane cloud forests, where biodiversity is very high. Halpin and Smith (1991) identify three types of changes in the areal arrangement of ecoclimatic zones in Costa Rica from four GCM models (UKMO, GISS, OSU, and GFDL). The first change is a strong trend toward displacement of montane and subalpine zones by warmer pre-montane climate types. The second change indicates potential heat stress in vegetation, and the third is a change in all altitudinal levels toward warmer climate types.

Villers-Ruiz and Trejo-Vázquez (1997) determined the vulnerability of Mexican forest ecosystems and forestry areas to climate change under two climate change scenarios, considering doubled-CO_2 concentrations (CCCM and GFDL-R30 models). They used Holdridge’s life zones classification for their analysis. Their results showed that the most affected life zones would be temperate cold and warm forests. They conclude that increases in temperature and decreases in precipitation would reduce the extent of cool temperate and warm temperate life zones but would increase dry and very dry tropical forest zones.

The most affected natural protected areas in Mexico would be those located in the northern and western regions of the country (Villers-Ruiz and Trejo-Vázquez, 1998). Similarly, the most affected forest exploitation areas would be those located in the western part of Mexico. These changes suggest that life zones that sustain temperate desert, warm temperate desert, and cool temperate wet forest would disappear or would be severely reduced (Villers-Ruiz and Trejo-Vázquez, 1998). These changes would put national cellulose and paper production at risk because high and medium forestry production areas are located in the northern and western states of Mexico (Vargas-Pérez and Terrazas-Domínguez, 1991). Cool, temperate moist and wet forests (coniferous and oak forests) currently occupy these zones.

Natural protected areas would be affected by the change of their original vegetation, causing a reduction of animal populations. Sierra de Manantlán and the Monarch Butterfly reserves are examples of climate change impacts on natural protected areas (Villers-Ruiz and Trejo-Vázquez, 1998).

The severe drought during early 1998, associated with an El Niño event, resulted in an unusually large number of forest fires and severe economic losses (Palacio *et al*., 1999). Cairns *et al*. (2000) estimates fuel consumption and coal emission in tropical Mexico for those events. The land-use/land-cover classes most extensively impacted were evergreen tropical forests and fragmented forests. They point out that similar fire events may be expected more frequently in the future if global change shifts toward a warmer and drier climate. The atmospheric consequences of those events were continuous emission of smoke to the United States for a large period of time (Wright, 1999). The costs from droughts and forest fires in Mexico and Central America during El Niño were approximately US$600 million.

The effects of a strong El Niño event on terrestrial ecosystems of Peru and Ecuador are as relevant (with high possibility) as in the ocean and shores (Arntz and Fahrbach, 1996). Increases in precipitation were recorded in Ecuador, Colombia, and northern Peru during the 1982–1983 El Niño event, with a simultaneous decrease in rainfall southward. Increases in precipitation also were recorded during the 1941 El Niño event. However, the increase in rainfall should not be assumed to be homogeneous. Whereas significant increases have been recorded in northern Peru, Ecuador, and even Colombia, severe droughts occurred around the Titicaca region and in northern Chile. In the highlands of the Andes as well, a north-south gradient in rainfall has been observed during El Niño events.

Increases in precipitation during El Niño events result in enhanced vegetation cover (from 5 to 89%) and primary productivity (from 0.005 to 3.5 t yr^{-1}) in coastal desert ecosystems. In northern Peru, strong El Niño events increase not only the ephemeral vegetation but also seed germination and seedling recruitment of woody species. Increases in precipitation from 20 mm (1996) to more than 1,000 mm (December 1997 to May 1998) have been recorded in Belizario in northern Peru. This increase in rainfall was correlated with a significant increase in annual NPPof the herb layer in a dry Prosopis pallida woodland, from almost zero in December 1997 to 0.51 g^{-2} yr^{-1} in February 1998. In the same region, the annual NPPof the shrub and tree layers also were significantly higher during the El Niño event, but fruit productivity decreased as a result of the mechanic effect of rain drops on buds, flowers, and immature fruits. Demographic explosions of two land snails were observed (Torres Guevara, 1992) during the increase in vegetation cover and annual NPP in northern Peru during 1998.

Besides the foregoing observations, little information has been reported about the explosive development of plant cover during strong El Niño events. Moreover, no data are available about the way in which this enhanced annual NPP impacts wildlife and range activities. According to Arntz and Fahrbach (1996), however, during this vegetation “explosion,” insects, snails, and other invertebrates increase in number and diversity. Consequently, vertebrates such as rodents, birds, and foxes benefit from a diversified and enriched diet. Observational studies confirm a significant increase in the density of rodents (Muridae and Cricetidae), followed by an increase in the activity of foxes (*Dusicyon culpaeus*). The considerable increase in the density of insects and rodent populations has a direct impact on agriculture. Damage associated with the incidence of pests on crops is further aggravated by the occurrence of floods.

Extraordinarily strong precipitation during El Niño events is not restricted to the continent. The Galápagos Islands also were affected by increased rainfall during 1983. As in continental ecosystems, enhanced annual NPPhad direct consequences on the densities of species in higher trophic levels (Tarazona and Valle, 1999).

As a consequence of the unusual combination of climatic and meteorological conditions attributed to the El Niño before and after the winter of 1997–1998, fires had a particularly strong effect on forests in Mexico. The number of fires was twice the average for the period 1992–1997 and 35% higher than the historical high mark recorded in 1988. The area affected was three times larger than the average for the same period (Barkin and García, 1999). Economic losses from those fires were estimated to be about US$230 million (Delgadillo *et al.*, 1999). Following the increase in rainfall associated with the strong El Niño event in 1982–1983, the next 2 years were exceptionally dry and cold in the Galápagos. Most of the plant biomass produced during the rainy years died back and accumulated as a result of the low decomposition rate. This increase in dry biomass is directly associated with the occurrence of fires affecting large areas. Recovery of plant cover after fires has been different in grasslands and woody vegetation. Whereas species diversity in grasslands has increased, fires had dramatic effects on woody vegetation because many trees and shrubs were severely affected by underground fires (Arntz and Fahrbach, 1996).

Scenarios of climate change for Latin America mountain areas are highly uncertain because available GCMs do not provide sufficiently accurate local predictions. Glacial retreat is underway in various parts of the Andes and in the ice fields at the southern tip of the continent (Canziani *et al.*, 1998). Shifting of ecosystems upslope is expected to result in loss of some vegetation types and increased vulnerability to genetic and environmental pressures.

14.2.1.5. *Biodiversity*

Latin America is known as home to some of the Earth's greatest concentrations of biodiversity (Heywood and Watson, 1995; Harcourt and Sayer, 1996). Seven of the world's most diverse and threatened areas are in Latin America and the Caribbean (Myers *et al.*, 2000). Of these, three rank among the world's five most critical hotspots. The tropical Andes qualifies as one of the world's two hyper-hot areas for its exceptional numbers of endemic plants and endemic vertebrates—the highest in the world. Maintenance of this diversity depends on the continued existence of representative areas of natural ecosystems (Fearnside and Ferraz, 1995; Fearnside, 1999). Dinerstein *et al.* (1995) have divided Latin America into 191 terrestrial "ecoregions" and collated information on the biodiversity importance and degree of risk of each in a systematic fashion to establish priorities for conservation. Many ecosystems already are at risk, without additional stresses expected from climatic change: 48% of all ecoregions are critical (18%) or endangered (30%); 32% are vulnerable, 16% are relatively stable, and 5% are relatively intact. Ecuador holds the distinction of being wholly covered by ecoregions with top priority at the regional level. The impacts of climate change can be expected to increase the risk of biodiversity loss in Latin America.

Central America has about 8% of the world's biodiversity concentrated in only 0.4% of the emerged surface of the planet. More than 15,000 species of plants and 1,800 species of vertebrates have been identified in the region. There are high quantities and variety of coastal wetlands in Central America. Central America's unique location between the Pacific Ocean and the Caribbean Sea—along with extreme climatic variations, tidal patterns, and geology—make these coastal wetlands among the most productive in the world (Tabilo-Valdivieso, 1997).

In addition to the loss of genetic resources, loss of productivity, and loss of ecosystem buffering against ecological perturbation, loss of biodiversity also may alter or impair the services that ecosystems provide (Naeem *et al.*, 1994). For a 2xCO_2 scenario, surface relative humidity zones shift upward by hundreds of meters during the winter dry season, when these forests typically rely mostly on moisture from cloud contact (Leo, 1995). At the same time, an increase in the warmth index implies increased evapotranspiration; this combination of reduce cloud contact and increased evapotranspiration could have serious conservation implications, as indicated in studies in anurans (Donnelly and Crump, 1998). The results of Pounds *et al.* (1999) indicate the association in populations of birds, lizards, and anurans with the same climatic patterns, implying a broad response to regional climate change. Other studies inspired by the climate-linked epidemic hypothesis have found that dry weather in 1983 increased the vulnerability of harlequin frogs (*Atelopus varius*) to lethal parasites along one stream (Crump and Pounds, 1985, 1989).

Suárez *et al.* (1999) have found that the coastal biodiversity (flora and fauna) in Cuba will be most affected by sea-level rise. Adaptation options include establishing a national legal system and a national strategy for conserving biodiversity that includes terrestrial, marine, or coastal reserves.

14.2.2. *Agriculture and Plantation Forestry*

14.2.2.1. *Arable Farming and Tree Crops*

Agricultural lands (excluding pastures) represent approximately 19% of the land area of Latin America. Over the past 40 years, the contribution of agriculture to the GDP of Latin American countries has been on the order of 10%. Agriculture remains a key sector in the regional economy because it employs an important segment (30–40%) of the economically active population. It also is very important for the food security of the poorest sectors of the population.

Arable farming is based on annual crops of cereals (wheat, maize, barley, rice, oats), oil seeds (soybean, peanuts, sunflower), vegetables/tubercles (potatoes, cassava), and a variety of perennial grasses, including specialty crops such as cotton, tobacco, tea, coffee, cacao, sugarcane, and sugar beet. Major tree/shrub crops include a large variety of fruits, oil palm, and others. This farm production has given rise to associated activities—such as beekeeping and bee products—as well as important agro-industries that produce valuable incomes in countries that already have developed their own markets and exporting lines.

Although the more important commercial agriculture and agro-industry businesses are well developed in a few countries, many Latin American economies rely on small farming system production. In smaller and poorer countries, such as rural communities in Central America and the Andean valleys and plateaus, agriculture is the basis of subsistence lifestyles and the largest user of human capital. For these countries, agriculture is the main producing sector; it undoubtedly is severely affected by climate variations and would be seriously influenced by climate change (Rosenzweig and Hillel, 1998).

Extremes in climate variability (e.g., the Southern Oscillation) already severely affects agriculture in Latin America. In southeastern South America, maize and soybean yields tend to be higher than normal during the warm Southern Oscillation and lower during the cold phase (Berlato and Fontana, 1997; Grondona *et al*., 1997; Magrin *et al*., 1998; Baethgen and Romero, 2000). Contributions to variability as a result of global warming and/or reduction in evapotranspiration from forest loss would be added to this background variability, thereby aggravating losses caused by extreme events.

Land-use choices will be affected by climate change. For example, increasing precipitation in marginal areas could contribute to an increase in cropped lands (Viglizzo *et al*., 1995). On the other hand, more favorable prices for grain crops relative to those for cattle are causing an increase in cultivated lands (Basualdo, 1995). The continued global trend to replace subsistence with market crops also creates an increasing threat to soil sustainability and enhances vulnerability to climate change**.**

Global warming and CO_2 fertilization effects on agricultural yields vary by region and by crop. Under certain conditions, the positive physiological effects of CO_2 enrichment could be countered by temperature increases—leading to shortening of the growth season and changes in precipitation, with consequent reductions in crop yields. Reduced availability of water is expected to have negative effects on agriculture in Mexico (Mundo and Martínez-Austria, 1993; Conde *et al*., 1997b). However, increases in temperature would benefit maize yields at high altitudes and lower the risk of frost damage (Morales and Magaña, 1999). Several studies were carried out in the region to assess the impact of climate change on annual crop yields. Most of these studies use crop simulation models with GCMs and incremental (temperature and precipitation) scenarios as climatic inputs. Baethgen and Magrin (1995) have shown that winter crop yields in Uruguay and Argentina are more sensitive to expected variations in temperature than precipitation. Under nonlimiting water and nutrient conditions and doubled-CO_2, the results for Argentina have shown that maize, wheat, and sunflower yield variations are inversely related to temperature increments, whereas soybean would not be affected for temperature increments up to 3°C (Magrin *et al*., 1997b, 1999a,b,c). Results obtained under rainfed conditions for different crops and management approaches in the region are summarized in Table 14-5; most of these results predict negative impacts, particularly for maize.

Adaptive measures to alleviate negative impacts have been assessed in the region. In Mexico, Conde *et al*. (1997a) found that increasing nitrogen fertilization would be the best option to increase maize yields, although it would not be economically feasible at all levels. In Argentina, the best option to improve wheat, maize, and sunflower yields would be to adjust planting dates to take advantage of the more favorable thermal conditions resulting from fewer late frosts (Travasso *et al*., 1999). However, this adaptive measure would be insufficient for maintaining actual wheat and maize yield levels. Genetic improvement will be necessary to obtain cultivars that are better adapted to the new growing conditions. For wheat and barley crops in Uruguay and Argentina, a longer growth season could be achieved by increasing photoperiodical sensitivity (Hofstadter *et al*., 1997; Travasso *et al*., 1999).

Subsistence farming could be severely threatened in some parts of Latin America. The global agricultural model of Rosenzweig *et al.* (1993) identifies northeastern Brazil as suffering yield impacts that are among the most severe in the world (see Reilly *et al*., 1996; Canziani *et al*., 1998; Rosenzweig and Hillel, 1998). Because northeastern Brazil is home to more than 45 million people and is prone to periodic droughts and famines even in the absence of expected climate changes, any changes in this region would have major human consequences.

Climate changes can be expected to lead to changes in soil stocks of carbon and nitrogen. In the Argentinean pampas, chemical degradation of soils, based on climate changes predicted by the GISS GCM (Hansen *et al*., 1988) at an atmospheric CO_2 concentration of 550 ppm, would reduce organic nitrogen by 6–10% and organic carbon by 7–20% in the topsoil as a result of lower dry-matter production and an increased mineralization rate (Díaz *et al*., 1997).

Tree crops in locations where frost risk presents a limitation—such as coffee in Paraná, Brazil—benefit from higher minimum temperatures resulting from global warming (Marengo and Rogers, 2000).

14.2.2.2. Ranching

Ranching is a major land use in many parts of Latin America. In the three countries that dominate the region's agriculture and ranching sector (Brazil, Argentina, and Mexico), pastures occupy four to eight times more area than agriculture (Baethgen, 1997). In much of Latin America, livestock is almost exclusively raised on rangelands, with no storage of hay or other alternative feeds. Grass production in rangelands depends on rainfall, and limited grass availability during dry periods limits cattle stocking rates over most of the region. In areas that are subject to prolonged droughts, such as northeastern Brazil and many rangeland areas in Mexico, production would be negatively affected by increased variability of precipitation from climate change. In the case of cattle in central Amazonia (várzea), higher peak flood stages would cause losses to cattle kept on platforms (marombas) during the high-water period.

In Argentina, some cattle are fed on alfalfa and other forage crops. A 1°C rise in temperature would increase alfalfa yields by 4–8% on average for most varieties, but yields would be reduced by 16–25% in areas north of 36°S and increased by 50–100% south of this latitude (Magrin *et al*., 1997b).

14.2.2.3. Plantation Silviculture

Plantation forestry is a major land use in Brazil and is expected to expand substantially over coming decades (Fearnside, 1998). Climatic change can be expected to reduce silvicultural yields to the extent that the climate becomes drier in major plantation states such as Minas Gerais, Espírito Santo, São Paulo, and Paraná as a result of global warming and/or reduced water vapor transport from Amazonia (e.g., Eagleson, 1986). Dry-season changes can be expected to have the greatest impact on silvicultural yields. Water often limits growth during this part of the year under present conditions, yet there may be water to spare during the rainiest part of the year. In areas outside of

***Table 14-5**: Assessments of climate change impacts on annual crops in Latin America.*

Study	Climate Scenario	Scope	Crop	Yield Impact (%)
Downing, 1992	+3ºC -25% precipitation	Norte Chico, Chile	Wheat	decrease
			Maize	increase
			Potato	increase
			Grapes	decrease
Baethgen, 1994	GISS, GFDL, UKMO	Uruguay	Wheat	-30
			Barley	-40 to -30
de Siqueira *et al*., 1994	GISS, GFDL, UKMO	Brazil	Wheat	-50 to –15
			Maize	-25 to –2
			Soybeans	-10 to +40
Liverman and O'Brien, 1991	GFDL, GISS	Tlaltizapan, Mexico	Maize	-20 -24 -61
Liverman *et al*., 1994	GISS, GFDL, UKMO	Mexico	Maize	-61 to –6
Sala and Paruelo, 1994	GISS, GFDL, UKMO	Argentina	Maize	-36 to -17
Baethgen and Magrin, 1995	UKMO	Argentina Uruguay (9 sites)	Wheat	-5 to -10
Conde *et al*., 1997a	CCCM, GFDL	Mexico (7 sites)	Maize	increase-decrease
Magrin *et al*., 1997a	GISS, UKMO, GFDL, MPI	Argentina (43 sites)	Maize	-16 to +2
			Wheat	-8 to +7
			Sunflower	-8 to +13
			Soybean	-22 to +21
Hofstadter *et al*., 1997	Incremental	Uruguay	Barley	-10[a] -8 to +5[b]
			Maize	-15[c] -13 to +10[b]

[a] For 1ºC increase.
[b] Change of -20 to +20% in precipitation.
[c] For 2ºC increase.

Brazil's extreme south, annual rings that are evident in the wood of plantation trees correspond to dry (as opposed to cold) seasons.

The effect of precipitation changes on plantation yields can be approximated by using a regression equation developed by Ferraz (1993) that relates biomass increment in Eucalyptus to precipitation at three sites in the state of São Paulo (Fearnside, 1999). UKMO model results (Gates *et al*., 1992) indicate that annual rainfall changes for regions of Brazil would cause yields to decrease by 6% in Amazonia and 8% in southern Brazil and increase by 4% in the northeast. During the June-July-August (JJA) rainfall period, yields would decrease by 12% in Amazonia, 14% in southern Brazil, and 21% in the northeast (Fearnside, 1999).

The foregoing discussion of precipitation decreases considers only the effect of global warming. Brazil is likely to suffer additional losses of precipitation as a result of reductions in evapotranspiration caused by deforestation in Amazonia (see Section 14.5.1.1.1). Some of the water vapor originating in Amazonia is transported to southern Brazil (Salati and Vose, 1984; Eagleson, 1986). Decreased water vapor supply to southern Brazil, where most of the country's silviculture is located, would aggravate precipitation declines stemming from global warming.

The direct effects of rainfall reduction on yields are likely to underestimate the true effect of climate change. Synergistic effects with other factors could reduce yield substantially more—for example, through attack by pests (Cammell and Knight, 1992).

Adrier climate in plantation areas also could be expected to lead to greater fire hazard. Fire is a problem in plantation silviculture even in the absence of climatic change, requiring a certain level of investment in fire control and a certain level of losses when burns occur. Pine plantations in Paraná require continuous vigilance (Soares, 1990). Eucalyptus also is fire-prone because of the high content of volatile oils in the leaves and bark.

Temperature changes can affect plantation yields. The models reviewed in the IPCC's Second Assessment Report (SAR) indicate a temperature increase of 2–3°C in Amazonia (Mitchell *et al.*, 1995; Kattenberg *et al.*, 1996). Considering a hypothetical increase of 1.5°C by the year 2050 in Espírito Santo and Minas Gerais, Reis *et al*. (1994) conclude that the present plantation area would have to be moved to a higher elevation (a shift that is considered impractical) or the genetic material would have to be completely replaced, following the global strategy proposed by Ledig and Kitzmiller (1992). In addition to direct effects of temperature considered by Reis *et al.* (1994), temperature increases have a synergistic effect with drought; the impact of dryness is worse at higher temperatures (lower elevations) as a result of higher water demands in plantations.

CO_2 enrichment would be beneficial for plantations. Higher atmospheric concentrations of CO_2 increase the water-use efficiency (WUE) of Eucalyptus. Photosynthetic rate increased in these experiments from 96% (*E. urophylla*) to 134% (*E. grandis*). Growth of different plant parts showed similar responses. Higher levels of CO_2 also stimulate nitrogen fixation, which could be expected to lower the fertilizer demands of plantations (Hall *et al*., 1992).

Climatic change would require larger areas of plantations (and consequently greater expense) to meet the same levels of demand. The percentage increase in areas required can be greater than the percentage decline in per-hectare yields caused by climatic change because expansion of plantation area implies moving onto progressively poorer sites where productivity will be lower. Taking as examples rainfall reductions of 5, 10, 25, and 50%, plantation area requirements are calculated to increase as much as 38% over those without climatic change, which would bring the total plantation area by 2050 to 4.5 times the 1991 area (Fearnside, 1999).

14.2.3. Sea-Level Rise

14.2.3.1. General Impacts

Information on areas of land loss in several countries of Latin America as a result of sea-level rise is synthesized in Table 6-5 of the IPCC *Special Report on Regional Impacts of Climate Change* (IPCC, 1998). Fishing production is a sector that would suffer as a consequence of sea-level rise. Along the Central American coastline, sea-level rise will affect infrastructure, agriculture, and natural resources, as well as potentially exacerbate coastal erosion and salinization of aquifers and increase flood risks and the impact of severe storms (Campos *et al.*, 1997; MINAE-IMN, 2000).

Chapter 6 of the Special Report identified information on the economic cost of sea-level rise in Latin America as assessed by Saizar (1997) and Olivo (1997) for the Uruguayan and Venezuelan coastlines, respectively. Saizar (1997) assessed the potential impacts of a 0.5-m sea-level rise on the coast of Montevideo (Uruguay). Given no adaptive response, the cost of such a rise in sea level was estimated to be US$23 million, with a shoreline recession of 56 m and land loss of 6.8 ha. Olivo (1997) studied the potential economic impacts of a 0.5-m sea-level rise on the coast of Venezuela. At six study sites, she identified land and infrastructure at risk—such as oil infrastructure, urban areas, and tourist infrastructure. Evaluating four scenarios, Olivo (1997) suggests that Venezuela cannot afford the costs of sea-level rise, either in terms of land and infrastructure lost under a no-protection policy or in terms of the costs involved in any of three protection policies.

Coastal wetlands in the region endure the impact of population growth, expansion of the agricultural activity, and land-use changes.

Observed sea-level rise at the local or regional level in Latin America could be greater than the global average value (Field, 1995; Codignotto, 1997; Kjerve and Macintosh, 1997). Negative trends in river streamflow along the Patagonian coast may result in reduction of sediments toward deposition areas. Coastal erosion would be affected by this effect as well as increased sea level (Codignotto, 1997; Kokot, 1999).

14.2.3.1.1. Mangrove ecosystem

The response of mangrove forests to changes in sea level within 50–100 years under climate change conditions is complex and controversial; it depends on physiography as well as ecological and biological factors (Villamizar, 1994; Ellison and Farnsworth, 1996; Ewel and Twilley, 1998; Rull *et al*., 1999).

The land-building function of mangrove vegetation has very important implications in coastal management because it works as a natural barrier to protect adjacent agricultural land by reducing erosion caused by wave action, tides, and river flow. This is important for shallow estuaries that are prone to flooding, especially where the land is below sea level (Twilley *et al*., 1997; Villamizar and Fonseca, 1999).

In the tropical Americas, the loss of coastal forests, mainly mangroves, occurs at a rate of approximately 1% yr^{-1}. The rate is much faster in the Caribbean—approximately 1.7% yr^{-1} (Ellison and Farnsworth, 1997). Because most commercial shellfish and finfish use mangal for nurseries and refuge, fisheries in mangrove regions are declining at a similar rate as mangrove communities (Martínez *et al.*, 1995; Ewel and Twilley, 1998).

14.2.3.1.2. Coral reefs

The second largest coral reef system in the world dominates the offshore area of the western Caribbean (Milliman, 1993), and all but the northern Gulf coast have extensive reef systems. Growth of individual coral organisms is estimated to be 1–20 cm yr^{-1} (Vicent *et al*., 1993), and reef growth rates as a whole are known to be up to 1.5 cm yr^{-1} (Hendry, 1993). Reefs that accumulate at these rates could keep pace with a sea-level rise of 20 cm by 2025 (UNEP, 1993) if other factors do not alter growth conditions.

Accurate predictions on the effect of sea-level rise may be possible in reefs that already have been physically and biologically monitored, such as in Panama, Jamaica, Puerto Rico, and Belize (UNEP, 1993; Gischler and Hudson, 1998).

14.2.3.1.3. Socioeconomic issues

Latin America coastal zones with economies that are based in fishing and tourism are particularly vulnerable to physical changes associated with sea-level rise.

Tourism is one of the most important industries in the region, especially in the Caribbean. Shoreline migration will create new areas of economic opportunity as new beaches are built, but protection, replenishment, and stabilization of existing beaches represents a principal socioeconomic impact. It is difficult to separate the impact of climate-induced sea-level rise from erosion associated with the persistent interaction of the sea on the coast. In addition, certain sand-mining practices (such as in Trinidad and Tobago) already have important effects on the ecosystem. Indirect socioeconomic effects on tourism from increasing pollution, coral reef mortality, and storm damage also are involved (UNEP, 1993).

Latin American economies could be severely affected by climate change. Coastal wetlands in Central America could generate US$750 million. Shrimp fisheries at the *Estero Real* in Nicaragua, which could provide US$60 million annually to the economy of the country, and the Gulf of Fonseca—which supplies important fishing, firewood, and transport to the rural communities of El Salvador, Honduras, and Nicaragua—could be affected by sea-level rise (Quesada and Jiménez, 1988).

Socioeconomic issues in the context of local response to global change—such as tourism, settlements and structures, and cultural heritage—and the influence of tropical storms are considered most important regarding levels of vulnerability (Mainardi, 1996; Tabilo-Baldivieso, 1997; Windovoxhel *et al*., 1998). Approximately 1,600 km of coral reefs and 870 km of mangroves are located in the region of Central America (Tabilo-Valdivieso, 1997). More than 15,000 species of plants and 800 species of vertebrates identified in the region would be at risk from sea-level rise, along with resources for rural communities (about 450,000 people) that inhabit the coastal areas of Central America (Windovoxhel *et al*., 1998).

14.2.3.2. Ecological and Local Community Values

Many local communities depend on coastal wetlands for survival; they use a wide range of natural products from the swamps and their surrounding waters (Field, 1997; RAMSAR, 1999). As Section 6.5.4 points out, in some coastal societies, cultural values are of equal—or even greater—significance than economic values. This is particularly true in Ecuador and Colombia on the Pacific coast, as well as the most northern part of Venezuela and Brazil on the Atlantic coast, where shrimp farming and timber exploitation represent the most common uses (Schaeffer-Novelli and Cintron, 1993; Sebastiani *et al*., 1996; Trujillo, 1998). Girot (1991) identifies the landscape and the aesthetics and spirituality of local people as important social and cultural impacts in the Central American region. An increase in sea level could affect monuments and historic sites of Central America.

Patterns of human development and social organization in a community are important factors in determining the vulnerability of people and social institutions to sea-level rise and other coastal hazards. The most common problems in local subsistence economies in Latin America coastal zones relate to firewood, isolation from enforcement, shrimp ponds, cattle, clearing for village expansion, coconut plantation, and sewage and garbage disposal (Sebastiani*et al.*, 1996;Ellison and Fanrsworth, 1997).

14.2.4. Water Resources: Availability and Use

Water resources for domestic, industrial, and agricultural use, averaged per capita among Latin American countries, vary from 28,739 m^3 in Argentina (whose population is 34,587,000) to more than 472,813 m^3 in Suriname (whose population is 423,000) (see Appendix D of IPCC, 1998). These averages hide the enormous disparity in many areas, such as poor rural areas, which are ill-supplied. In some Latin American regions—especially in areas where it is possible that the combined effect of less rainfall and more evaporation could take place, leading to less runoff—global warming will substantially change the availability of freshwater. Watersheds in arid or semi-arid regions are especially sensitive because annual runoff already is highly variable (Medeiros, 1994). Watersheds in the southern hemisphere where snowmelt is an important source of runoff also can be severely affected (Basso, 1997). Vulnerability of oases between 29°S and 36°S to drier conditions in the high Andes can be observed (Canziani *et al.*, 1997)

Few specific water resources impact studies using climate change scenarios have been conducted in Latin America: Riebsame *et al.* (1995) studied the Uruguay River basin. In the study, all scenarios used indicated a shift of seasonality and a decrease in runoff during low-flow periods. For the Choqueyapu River (La Paz, Bolivia) under a UKMO-89 climate scenario, these studies projected an increase of discharge in the low-water period and in the months of December and January. For some other watersheds (Caire, Mamoré, Guadalquivir, and Miguillas), the magnitude and tendency of the results varies, depending on the scenario used (PNCC, 1997). For the Pirai River, located in a humid area and flowing through urban areas (Santa Cruz City), runoff increases under an increased precipitation scenario (PNCC, 2000). Estimates of water availability in Mexico and Central America (Izmailova and Moiseenko, 1998) indicate that about 70% of the population in those countries will live in regions with low water supply as soon as the first quarter of the 21st century. A study using climate scenarios from GFDL, GISS, and NCAR models, combined with incremental scenarios of 1–2°C temperature rise and 10% precipitation increase, found that decreasing precipitation in Mexico and El Salvador can cause a change in runoff by 5–7% but that in the winter runoff changes by only by 0.2–0.7%.

Potential changes in temperature and precipitation might have a dramatic impact on the pattern and magnitude of runoff, soil moisture, and evaporation, as well as the aridity level of some hydrological zones in Mexico (Mendoza *et al.*, 1997). A vulnerability study performed in conjunction with the National GHG Inventory in Argentina foresees a reduction in water availability as a result of changes in snowmelt in the high Andes. Similar studies in Peru show that warming has created several environmental hazards, such as avalanches in Peruvian Andean valleys, with a foreseen critical reduction of water resources for human and industrial consumption (Morales-Arnao, 1999).

Water use in Latin America is mainly for agricultural activities, averaging nearly 60% of total water use. It ranges from approximately 40% in Colombia and Venezuela to more than 75% in Argentina, Bolivia, Costa Rica, El Salvador, Ecuador, Guatemala, Honduras, Mexico, Panama, Paraguay, Suriname, and Uruguay (Canziani *et al.*, 1998). Even with a potential increase in water availability in some parts of northern Mexico (Mundo and Martínez-Austria, 1993; Magaña and Conde, 1998), demand for water from agricultural, urban, and industrial sectors has shown a much faster growth because of the rapid expansion of these sectors in recent decades.

Some hydrological scenarios for Cuba (Planos and Barros, 1999) show that a significant limitation of potential water resources will occur within the next century as a result of increments in evapotranspiration and changes in precipitation.

14.2.5. Human Health

Health impacts from climate change can arise via complex processes. The scale of these effects would depend primarily on the size, density, and wealth of human populations or communities (WHO, 1998). Extreme weather variability associated with climate change may add new stress to developing nations that already are vulnerable as a result of environmental degradation, resource depletion, overpopulation, or location (McMichael *et al*., 1996).

Persistent poverty and population pressure accompanied by inadequate sanitation and inadequate public health infrastructure will limit many populations' capacity to adapt (Kovats *et al*., 1998; Patz, 1998). Interaction between local environmental degradation and changes on a larger scale—climate change, population growth, and loss of biodiversity—may significantly influence effects on health (Haines and McMichael, 1997; WHO, 1998). The direct impacts of climate change depend mainly on exposure to heat or cold waves or extreme weather events, such as floods and droughts.

14.2.5.1. Effects of Changes in Climate Variables on Health

Kattenberg *et al.* (1996) made generalized tentative assessments concerning extreme weather and climate events. Studies in temperate and subtropical countries have shown increases in daily death rates associated with extreme outdoor temperatures (see Section 14.1.5; McMichael *et al*., 1996). Climate change scenarios constructed from three models have been used to estimate human mortality with changes in baseline climate conditions for Buenos Aires, Caracas, San José, and Santiago. In Caracas and San José, where present temperatures are close to the comfort temperature for all months, mortality rates (total, cardiovascular, and respiratory) increase for most of the climate change scenarios employed. However, decreases in winter mortality may offset excess summer mortality in cities with relatively colder climates, such as Santiago (Martens, 1998). People who are more than 65 years old are more temperature sensitive than younger people (Martens, 1998).

There is evidence that people living in poor housing conditions (crowded and poorly ventilated) and urban populations in developing countries are particularly vulnerable to thermal stress enhanced by rapid urbanization (urban heat island) because of few social resources and low preexisting health status (Kilbourne, 1989; Martens, 1998). Furthermore, in rural areas, the relative importance of temperature on mortality may be different from its effect on urban populations (Martens, 1998).

Prolonged heat can enhance production of smog and dispersal of allergens. Both effects have been linked to respiratory symptoms (Epstein, 2000). High temperatures and air pollutants, especially particulates, act synergistically to influence human health. This effect is occurring in large cities, such as Mexico City, Santiago, and more recently Buenos Aires, where such conditions enhance the formation of secondary pollutants (e.g., ozone—Escudero, 1990; Katsouyanni *et al*., 1993; Canziani, 1994). Saldivia (1994, 1995) has observed an increasing trend in the mortality of elderly people following peaks of air pollution in São Paulo. Daily mortality has been correlated mainly with temperature and ozone concentration, both measured the day before (Sartor *et al.*, 1995). Hyperthermic syndrome (heat stroke) affected children under 2 years old and people over 80 in Peru's coastal regions during the high temperatures of the El Niño phenomenon (Instituto Nacional de Salud, 1998a, 1999).

During droughts, the risk of wildfires increases, causing loss of green areas, property, livestock, and human life, as a result of increasing air pollution from suspended particles (OPS, 1998). The direct effects of wildfires on human health occur from burns and smoke inhalation (Kovats *et al*., 1999). In *Alta Floresta*, Brazil, there was a 20-fold increase in outpatient visits for respiratory disease in 1997 during a biomass smoke episode (Brauer, 1998).

Increased ambient temperature may have significant effects on the distribution and overgrowth of allergenic plants. Higher temperatures and lower rainfall at the time of pollen dispersal are likely to result in higher concentrations of airborne pollen during the peak season (Emberlin, 1994; Rosas *et al*., 1989). A relationship between concentrations of algae and weather parameters (temperature and vapor pressure) in Mexico has been correlated. Dispersion of algae has received much attention during recent years as a result of associated inhalant allergies and other respiratory disorders (Rosas *et al.*, 1989). The high degree of seasonality (dry-rainy season) in air-borne enteric bacterial, basidiomycete spore, particle, and protein concentrations also could be associated with temperature and vapor pressure in Mexico City (Rosas *et al*., 1994, 1995; Calderón *et al*., 1995). Thus, future changes in climatic variables might have an important effect in the distribution of air-borne bacteria, fungus, pollen, particles, and proteins whose allergenic properties have to be considered.

In 1998, there was an increase in cholera cases in Peru and Ecuador and other countries affected by weather disasters. Hurricane Mitch affected Guatemala (the number of cholera cases increased four-fold), Belize, and Nicaragua (the number of cholera cases was six times the usual number of reported cases) (OPS, 1999).

Global warming could increase the number and severity of extreme weather events, such as storms, floods, droughts, and hurricanes, along with related landslides and wildfires (IPCC, 1996). Such events tend to increase death and disease rates—directly through injuries or indirectly through infectious diseases brought about by damage to agriculture and sanitary infrastructure and potable water supplies (PAHO, 1998a). Floods and droughts could permanently or semi-permanently displace entire populations in developing countries, leading to overcrowding and diseases connected with it, such as tuberculosis and other air-borne and crowd diseases; adverse psychological effects; and other stresses (IPCC, 1996; McMichael and Kovats, 1998a,b; Epstein, 2000). Slums and shantytowns located on hills (e.g., Rio de Janeiro), as well as human settlements located in flood-prone areas, are particularly subject to periodic natural disasters that adversely affect human health and sanitary infrastructure (IPCC, 1996).

In developing countries, populations are becoming more rather than less vulnerable to disasters (McMichael and Kovats, 1998b). Natural disasters may be responsible for outbreaks of cholera, leptospirosis, malaria, and dengue (Moreira, 1986; PAHO, 1998a,b). Hurricane Mitch stalled over Central America in October 1998 for 3 days, claiming 11,000 lives. It was the most deadly hurricane to strike the western hemisphere in 2 centuries (Hellin *et al.*, 1999). After Mitch, Honduras reported thousands of cases of cholera, malaria, and dengue fever (PAHO, 1998a,b; OPS, 1999; Epstein, 2000). As the risk of flooding increases with climate change, so does the importance of the major drainage system, which will determine whether floodwaters drain in minutes, hours, or days (McMichael and Kovats, 1998b). Floodwaters can cause the release of dangerous chemicals from storage and waste disposal sites and precipitate outbreaks of vector- and water-borne diseases (Patz, 1998).

Indirect effects of disasters can damage the health care sector. After Hurricane Mitch, some countries in Central America regressed decades in health services and transport infrastructure, thereby making it more difficult to assist the affected population (OPS, 1999). Environmental refugees could present the most serious health consequences of climate change. Risks that stem from overcrowding include virtually absent sanitation; scarcity of shelter, food, and safe water; and heightened tensions—potentially leading to social conflicts (Patz, 1998). Weather disasters cause many deaths and have long-term impacts on communities, including psychological effects such as post-traumatic stress disorder (Kovats *et al*., 1998). In 1999, heavy rains on the coast of Venezuela displaced 80,000–100,000 people and caused 20,000–50,000 deaths, as well as enormous damage in infrastructure (PNUD/CAF, 2000).

14.2.5.2. Vector-Borne Diseases

Arthropod vector organisms for vector-borne diseases (VBDs) are sensitive to climatic and hydrometeorological conditions (especially temperature and humidity, stagnant water pools, and ponds), as are life-cycle stages of the infecting parasite within the vector (Bradley, 1993; Haines *et al*., 1993; Curto de Casas *et al*., 1994; Ando *et al*., 1998). Hence, the geographic range of potential transmission of VBDs may change under conditions of climate change (Leaf, 1989; Shope, 1991; Carcavallo and Curto de Casas, 1996; McMichael *et al*., 1996; Patz *et al*., 1996; WHO, 1998). Several studies have concluded that temperature affects the major components of vectorial capacity (Carcavallo *et al*., 1998; Carcavallo, 1999; Moreno and Carcavallo, 1999).

Mosquitoes, in particular, are highly sensitive to climatic factors (Curto de Casas and Carcavallo, 1995). *Anophelinespp*. and *Aedes aegypti* mosquitoes have established temperature thresholds for survival, and there are temperature-dependent incubation periods for the parasites and viruses within them (the extrinsic incubation period) (Curto de Casas and Carcavallo, 1995; de Garín and Bejarán, 1998a,b; Epstein *et al*., 1998; de Garín *et al*., 2000). Climate change may influence the population dynamics of vectors for Chagas' disease (Burgos *et al*., 1994), as well as the number of blood-feedings of mosquitoes and, therefore, the possibilities of infective direct contacts (Catalá, 1991; Catalá *et al*., 1992).

Of relevance to infectious disease distribution, minimum temperatures are now increasing at a disproportionate rate compared to average and maximum temperature (Karl *et al*., 1995). Such conditions may allow dengue and other climate-sensitive VBDs to extend into regions that previously have been free of disease or exacerbate transmission in endemic parts of the world. Temperature is one of the factors that can influence the seasonal transmission of malaria. Near the equator in Iquitos, Peru, seasonality in transmission is driven by small temperature fluctuation (1–2°C) (Patz *et al*., 1998). The current and projected expansion of the range of vector species into the subtropics and to higher elevations warrant heightened entomological and epidemiological surveillance and control in highland areas and for populations living on the fringes of regions that now are affected (Epstein *et al*., 1998).

Reemergence of dengue fever in Colombia followed reinvasion of the country by the principal mosquito vector (*Aedes aegypti)*, and the disease hit with large upsurges following periods of heavy rain (Epstein *et al*., 1995). The mosquito vector for dengue and yellow fever has been reported at an elevation of 2,200 m in Colombia (Suárez and Nelson, 1981).

Climate variability, environmental change, and lack of control of vector reproduction already have affected the distribution of VBDs. In Honduras, a sustained increase in ambient temperature makes the southern part too hot for anopheline mosquitoes, and reported cases of malaria have dropped off. Large areas of northeast tropical rainforest have been cleared, and migrants concentrated there tend not to be immune to malaria (Almendares *et al*., 1993).

14.2.5.3. Water-Borne Diseases

Extremes of the hydrological cycle, such as water shortages and flooding, could worsen the diarrhea disease problem. In developing countries, water shortages cause diarrhea through poor hygiene. On the other extreme, flooding can contaminate drinking water from watershed runoff or sewage overflow (Patz, 1998). Depending on the disease agent and its transmission maintenance cycle, the effect may be an increase or a decrease in the incidence of infectious diseases (Gubler, 1998).

Between the first case of the current cholera outbreak—reported in Peru in 1991—and December 1996, cholera spread to more than 21 countries, resulting in almost 200,000 cases and more than 11,700 reported deaths (OPS, 1998). Colwell and Huq (1994) have collected data in Bangladesh and Peru suggesting that cholera has a complex route of transmission that is influenced by climate—in particular, SST and sea-level variations (Lobitz *et al*., 2000). It has been suggested that the spread of *Vibrio cholerae* may be related to the development of various algae and zooplankton. Extensive studies during the past 25 years confirming the hypothesis that *V. cholerae* is autochthonous to the aquatic environment and is a commensal of zooplankton (i.e., copepods), combined with the findings of satellite data analyses, provide strong evidence that cholera epidemics are climate-linked (Lobitz *et al*., 2000). Increased coastal algae blooms (which are sensitive to changes in climatic conditions) therefore may amplify *V. cholerae* and enhance transmission (Epstein, 2000). Furthermore, *V. cholerae* follows a salinity gradient, which might bring the disease to new shores if sea level rises (WHO, 1998).

In 1998, Ecuador's vulnerability to cholera increased as a result of climatic phenomena (OPS, 1999). In 1997–1998 in Peru, the same areas affected by climatic phenomena showed an increase in cholera cases, probably as a result of floods, problems with drainage, and food contamination in shelters (OPS, 1999). In Peru, persistence in transmission of diarrheal diseases such as *Salmonella typhi* and cholera was related to changes in environmental, climatic, and sanitary conditions (Carrillo, 1991a,b).

Floods foster fungal growth and provide new breeding sites for mosquitoes, whereas droughts concentrate microorganisms and encourage aphids, locusts, and whiteflies and—when interrupted by sudden rains—may spur explosions of rodent populations (Epstein and Chikwenhere, 1994).

The first recorded outbreak of Weil's disease (leptospirosis) in Colombia occurred mainly in children from poor neighborhoods. Symptoms of leptospirosis are similar to those of dengue, and the former can be fatal rapidly in patients not receiving proper treatment. The probable agents and disease seem to be linked with rodents escaping from floods (Epstein *et al*., 1995).

In Cuba, acute diarrheal diseases occur more often during the warm and rainy period, when ecological conditions are favorable for reproduction of bacteria, viruses, and protozoa. Acute respiratory infection reports diminish after climatic conditions become warmer, more humid, and thermally less contrasting (Ortiz *et al*., 1998). In Mexico, some rain in semi-arid zones has caused bubonic plague outbreaks (Parmenter *et al*., 1999).

14.2.5.4. Effects of El Niño Phenomenon on Health

There is good evidence that the ENSO cycle is associated with increased risk of certain diseases (PAHO, 1998b). ENSO events may affect the distribution (reproduction and mortality) of disease vectors (Epstein *et al.*, 1998). El Niño events raise SST over the tropical Pacific, affecting some pathogenic agents. McMichael and Kovats (1998b), Patz (1998), and Instituto Nacional de Salud (1998a,b) have speculated that the last cholera outbreak in Peru, beginning in 1991, was linked with an El Niño phenomenon (1990–1995). The outbreak spread to most of the South American subcontinent, including places as far away as Buenos Aires (OPS, 1999). de Garín *et al*. (2000) have reported that El Niño has important impacts in andean population; they found large amounts of the insect, as well as eggs for the next period, in the northern part of Argentina.

Higher temperatures over coastal Peru associated with ENSO may have an impact on gastrointestinal infections. Salmonella infections increased after a flood in Bolivia, which resulted from the El Niño event of 1983 (Valencia Tellería, 1986). Salazar-Lindo *et al*. (1997) report that the number of patients with diarrhea and dehydration admitted to a rehydration unit in Lima, Peru, was 25% higher than usual during 1997, when temperatures where higher than normal as a result of the emerging El Niño. Increases in the incidence of acute diarrheas and acute respiratory diseases were recorded in Bolivia (Valencia Tellería, 1986) and Peru (Gueri *et al*., 1986).

The effects of natural events vary by region, and the same weather condition may have the opposite effect in different areas for the same disease (e.g., a dry year may induce malaria epidemics in humid regions but cause malaria decreases in arid regions) (McMichael and Kovats, 1998b). For example, ENSO has been associated with severe drought in Iquitos, Peru, and the state of Roraima, Brazil, where malaria cases have drastically decreased (OPS, 1998; Confalonieri and Costa-Díaz, 2000). In Venezuela, malaria mortality has been shown to be more strongly related to the occurrence of drought in the year preceding outbreaks than to rainfall during epidemic years (Bouma and Dye, 1997). The El Niño phenomenon appears to be responsible in particular for serious epidemics in Peru, including one of malaria in 1983 (Moreira, 1986; Russac, 1986; Valencia Tellería, 1986), as well as cutaneous diseases, leptospirosis, and respiratory infections in 1998 (Instituto Nacional de Salud, 1998b). Compared with other years, malaria cases in Colombia increased 17.3% during an El Niño year and 35.1% in the post-El Niño year. Upsurges of malaria in Colombia during El Niño events are associated with its hydrometeorological variables—in particular, the increase in air temperature that enhances reproductive and biting rates and decreases the extrinsic incubation period, as well as changes in precipitation rates that favor formation of ponds and stagnant pools and thus create more mosquito breeding sites (Poveda and Rojas, 1997; Poveda *et al*., 1999a,b).

Global analyses have shown no association between ENSO and the number of flood disasters (Dilley and Heyman, 1995) or between ENSO and the numbers of persons affected by floods and landslides (Bouma *et al*., 1997). However, the number of persons affected by landslides, particularly in South America, increases in the year after the onset of El Niño (Bouma *et al*., 1997). In 1983, the impacts of El Niño in Peru increased total mortality by nearly 40% and infant mortality by 103% (Toledo-Tito, 1997).

Predicting malaria risk associated with ENSO and related climate variables may serve as a short-term analog for predicting longer term effects posed by global climate change. The ability to predict years of high and low risk for malaria can be used to improve preventive measures (Bouma *et al*., 1997).

14.2.5.5. Effects on Food Production and Safety

Climate change would affect human health indirectly by threatening food production, as a result of increased temperature, ultraviolet irradiation, sea-level rise, changes in pest ecology, ecological disruption in agricultural areas as a result of disasters, and socioeconomic shifts in land-use practices (Rosenzweig *et al*., 1993; Siqueira *et al*., 1994; Reilly *et al*., 1996; Haines and McMichael, 1997; Magrin *et al*., 1997c; Epstein *et al*., 1998). A link between El Niño and variation of the inter-tropical convergence zone and drought in northeastern Brazil has been described for many years (Hastenrath and Heller, 1977). Periodic occurrences of severe droughts associated with El Niño in this agriculturally rich region have resulted in occasional famines (Kiladis and Díaz, 1986; Hastenrath, 1995). Severe food shortages have occurred in this region in 1988 and 1998 (Kovats *et al*., 1999).

Developing countries already struggle with large and growing populations, and malnutrition rates would be particularly vulnerable to changes in food production (Patz, 1998). Changes in the distribution of plant pests have implications for food safety. Ocean warming could increase the number of temperature-sensitive toxins produced by phytoplankton, causing contamination of seafood more often and an increased frequency of poisoning. The rapid spread of cholera along the Peruvian coasts and the fact that the *V. cholerae* 01 isolates involved constitute a separate genetic variant that could be a result of environmental change (Wachsmuth *et al*., 1991, 1993)—as well as the ability of *V. cholerae* to survive in seawater and freshwater—make cholera a persistent health hazard (Tamplin and Carrillo, 1991). Thus, climate-induced changes in the production of aquatic pathogens and biotoxins may jeopardize seafood safety (IPCC, 1996). Increased ambient temperature has been associated with food poisoning; multiplication of pathogenic microorganisms in food is strongly dependent on temperature (Colwell and Huq, 1994; Bentham and Langford, 1995; Patz, 1998). This indicates the importance of ambient conditions in the food production process, including animal husbandry and slaughtering, to avoid the adverse effects of a warmer climate.

In Argentina, the heavily populated Paraná Delta could be seriously affected by even small changes in sea level (Kovats *et al*., 1998). The effects of sea-level rise may be counteracted by growing deltas as a result of the large amount of sediment coming down the Paraná and Uruguay Rivers from intense deforestation and consequential water erosion on the land of the upper basins.

Many glaciers and ice fields may soon disappear, potentially jeopardizing local water supplies that are critical for human consumption, regional agriculture, and hydroelectric power generation (Epstein *et al*., 1998). There is high confidence in the effects of warming on glaciers, which already are disappearing in Peru and decreasing in the high Andes between 29°S and 36°S (Canziani *et al*., 1997).

Climate changes are expected to have the greatest effect on health in developing nations in Latin America that already have poor and weak infrastructures. Linkages between local public health and issues of climate change must continue to be considered so that prevention and response mechanisms can be implemented against disease and other threats to human health (Kovats *et al*., 1998).

14.3. Synthesis

There is ample evidence of climate variability at a wide range of time scales all over Latin America, from intraseasonal to long term. For instance, at decadal scales, multiple climate records throughout the region consistently exhibit a shift in the mean during the mid-1970s, which could be a consequence of

Table 14-6*: Variability and impacts of El Niño and La Niña on several Latin American countries and subregions.*

Event	**Climatic/Hydrological Variable**	**Subregion or Country**	**Reference(s)**	**Observation Period**
El Niño[a]	Severe droughts[b] in recent decades	Mexico	Magaña and Conde, 2000	1958–1999[c]
	Severe droughts	Northeast Brazil	Silva Dias and Marengo, 1999	1901–1997
	Decrease in precipitation	Central America (Pacific)	Magaña and Conde, 2000	1958–1999
	Increase in precipitation	Central America (Atlantic)	Magaña and Conde, 2000	1958–1999
	Decrease in precipitation, soil moisture, river streamflow	Colombia	Poveda and Mesa, 1997 Carvajal *et al*., 1999 Poveda *et al*., 2001	1958–1995 1957–1997 1958–1998
	Increase in precipitation and floods	Northwest Peru	Marengo *et al*., 1998	1930–1998
	Decrease in precipitation during rainy season	Northern Amazonia and northeast Brazil	Aceituno, 1988; Richey *et al*., 1989; Marengo, 1992; Uvo, 1998	1931–1998
	Negative large anomalies of rainfall during rainy season	Northeast Brazil	Silva Dias and Marengo, 1999 Hastenrath and Greischar, 1993 Nobre and Shukla, 1996	1930–1998 1912–1989 1849–1984
	Increase in precipitation during November–January time frame	Argentina (Pampas region)	Barros *et al*., 1996; Tanco and Berry, 1996; Vila and Berri, 1996; Vila and Grondona, 1996; Magrin *et al*., 1998	1900–1996
	Intense snowfalls in high Andes mountains	Central western Argentina and central Chile	Canziani *et al*., 1997	1900–1995
	Increase in runoff	Chile and central western Argentina	Compagnucci *et al*., 2000 Compagnucci and Vargas, 1998	1906–1994 1909–1998

sudden changes in the climatology of the Pacific Ocean. These changes have important socioeconomic and environmental consequences that could be enhanced by global warming and its associated climate change.

Precipitation changes in Latin America do not follow a consistent trend. In northwestern Mexico there is a clear tendency for more winter precipitation, which has resulted in positive trends in river-water level. In north and northwestern Nicaragua, there is a negative trend in rainfall. In the Amazonian region, the most important finding is the presence of periods with relatively wetter or drier conditions that are more relevant than any unidirectional trend. Rainfall in north-northeast Brazil exhibits a weak positive trend. Precipitation in subtropical Argentina, Paraguay, and Brazil increased abruptly in the 1956–1990 period after a dry period from 1921 to 1995. In the Pampas, there was a positive trend in precipitation over the 1890–1984 period. At higher elevations in northwestern Argentina, records suggest an increase in precipitation over the past 200 years.

The Southern Oscillation is responsible for a large part of the climate variability at interannual scales in Latin America. The region is vulnerable to El Niño, with impacts varying across the continent. For example, El Niño is associated with dry conditions in northeast Brazil, northern Amazonia, the Peruvian-Bolivian Altiplano, and the Pacific coast of Central America, whereas southern Brazil and northwestern Peru exhibit anomalously wet conditions. Extensive studies of the Caribbean watersheds of Mexico and other countries show compelling evidence of more winter and less summer precipitation; in addition, the most severe droughts in Mexico in recent decades have occurred during El Niño years. In Colombia, La Niña is associated with heavy precipitation and flooding, whereas El Niño is associated with negative anomalies in precipitation and river streamflow. Drought also occurs in southern Brazil during the positive phase of the Southern Oscillation. If El Niño or La Niña were to increase, Latin America would be exposed to these conditions more often (see Table 14-6).

Warming in high mountain regions could lead to disappearance of significant snow and ice surfaces, which could affect mountain sport and tourist activities. Because these areas contribute to river streamflow, it also would affect water availability for irrigation, hydropower generation, and navigation, which represent important sources of income for some economies. It has been well-established that glaciers in Latin America have receded in recent decades.

It is well-established that Latin America accounts for one of the Earth's largest concentrations of biodiversity, and the impacts of climate change can be expected to increase the risk of biodiversity loss. Some adverse impacts on species that can be related to regional climate change have been observed, such as population declines in frogs and small mammals in Central America. Maintenance of remaining Amazonian forest is threatened by the combination of human disturbance and decreased precipitation from evapotranspiration loss, global warming, and El Niño. Fire in standing forest has increased in frequency and scale in Amazonia as a result of greater accumulation of deadwood in the forest from logging activity and from trees killed by past fires, more human settlement providing opportunities for fire initiation, and dry conditions

Table 14-6 (continued)

Event	Climatic/Hydrological Variable	Subregion or Country	Reference(s)	Observation Period
La Niña[d]	Heavier precipitation and floods	Colombia	Poveda and Mesa, 1997 Carvajal *et al*., 1999	1972–1992 1957–1997
	Decrease in precipitation during October–December time frame	Argentina (Pampas region)	Barros *et al*., 1996; Tanco and Berry, 1996; Vila and Berri, 1996; Vila and Grondona, 1996; Magrin *et al*., 1998	1900–1996
	Increase in precipitation, higher runoff	Northern Amazonia Northeast Brazil	Marengo *et al*., 1998 Meggers, 1994	1970–1997 Paleoclimate
	Severe droughts	Southern Brazil	Grimm *et al*., 1996, 2000	1956–1992
	Negative anomalies of rainfall	Chile and central western Argentina	Compagnucci, 2000	Paleoclimate

[a] Extremes of the Southern Oscillation (SO) are responsible in part for a large portion of climate variability at interannual scales in Latin America. El Niño (or ENSO) events represent the negative (low) phase of the SO.

[b] Prolonged periods of reduced summer soil moisture.

[c] Six El Niño events occurred during this period.

[d] La Niña is the positive (high) phase of the SO.

during ENSO events. Neotropical seasonally dry forest should be considered severely threatened in Mesoamerica.

Mortality of trees has been observed to increase under dry conditions that prevail near newly formed edges in Amazonian forests. Edges, which affect an increasingly large portion of the forest with the advance of deforestation, would be especially susceptible to the effects of reduced rainfall. In Mexico, deciduous tropical forest would be affected in approximately 50% of the area presently covered by these forests. Heavy rain during the 1997–1998 ENSO event generated drastic changes in the dry ecosystems of northern Peru's coastal zone. Increases in biomass burning in Amazonia affected by human activity and by climate increase wind-borne smoke and dust that supply nutrients to the Amazon forests. Global warming would expand the area that is suitable for tropical forests as equilibrium vegetation types. However, the forces driving deforestation make it unlikely that tropical forests will be permitted to occupy these increased areas. Land-use change interacts with climate through positive feedback processes that accelerate loss of humid tropical forests.

Sea-level rise will eliminate the present habitats of mangroves and create new tidally inundated areas to which some mangrove species may shift. Coastal inundation stemming from sea-level rise and riverine and flatland flooding would affect water availability and agricultural land. These changes can exacerbate socioeconomic and health problems in critical areas.

On a scale of decades to centuries, it is well-established that changes in precipitation and catchment runoff may have significant effects on mangrove forest communities. This also would affect the region's fisheries because most commercial shellfish and finfish use mangroves as nurseries and for refuge.

Studies in Argentina, Brazil, Chile, Mexico, and Uruguay, based on GCMs and crop models, project decreased yield for several crops (e.g., maize, wheat, barley, grapes), even when the direct effects of CO_2 fertilization and implementation of moderate adaptation measures at the farm level are considered. Predicted increases in temperature will reduce crops yields in the region by shortening the crop cycle. Although relationships between the amount of precipitation and crop yields are well-established, the lack of consistency in the results of different GCMs means that confidence in the estimated impacts of future precipitation on crop production is necessarily limited.

Over the past 40 years, the contribution of agriculture to the GDP of Latin American countries has been on the order of 10%. Agriculture remains a key sector in the regional economy because it employs 30–40% of the economically active population. It also is very important for the food security of the poorest sectors of the population. Subsistence farming could be severely threatened in some parts of Latin America (e.g., northeastern Brazil).

Evidence is established but incomplete that climate change would reduce silvicultural yields because water often limits growth during the dry season, which is expected to become longer and more intense in many parts of Latin America.

The scale of health impacts from climate change in Latin America would depend primarily on the size, density, location, and wealth of populations. Evidence has been established but incomplete that exposure to heat or cold waves has impacts on mortality rates in risk groups in the region.

Increases in temperature would affect human health in polluted cities such as Mexico City and Santiago. Ample evidence provides high confidence that the geographical distribution of VBDs in Peru and Cuba (e.g., cholera, meningitis) would change if temperature and precipitation were to increase, although there is speculation about what the changes in patterns of diseases would be in different places. It is well-established that weather disasters (extreme events) tend to increase death and morbidity rates (injuries, infectious diseases, social problems, and damage to sanitary infrastructure)—as occurred in Central America with Hurricane Mitch at the end of 1998, heavy rains in Mexico and Venezuela at the end of 1999, and in Argentina in 2000. It is well-established that the ENSO phenomenon causes changes in disease-vector populations and in the incidence of water-borne diseases in Brazil, Peru, Bolivia, Argentina, and Venezuela. It has been speculated that weather factors and climate change may affect the incidence of diseases such as allergies in Mexico. Increased temperature, ultraviolet radiation, sea-level rise, and changes in pest ecology may threaten food production in Argentina.

In summary, climate change already has a diverse array of impacts in Latin America. Projected future changes in climate, together with future changes in the vulnerability of human and natural systems, could lead to impacts that are much larger than those experienced to date.

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