Chapter 27. Central and South America

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Executive Summary

[to be developed]

27.1. Introduction

27.1.1. The Central and South America Region

In Central and South America, where the economies are highly sensitive to climate and the societies have a low resilience, climate change consequences have been identified as a major threat not only to the local economies but also to the food security (agriculture, hydroelectric production, water for irrigation, tourism, fisheries, near-coastal and near-river infrastructures). Climate variability in various time scales have been affecting the population and natural systems in these regions, and extremes in particular have affected large regions of Central and South America. Observed trends suggest increase in total rainfall in Southeastern South America, as well as rainfall reductions or increases have been noticed in large parts of tropical Central and South America, due to changes in tropical cyclones. In particular, the effects of climate change will likely heavily impact the region, where there remains a substantial, but intrinsically fragile, natural capital and where there are a number of climate-sensitive ecoregions. These climate-sensitive regions should be further characterized to reflect the relative vulnerability of dependent populations to climate impacts. The situation contrasts with a relatively modest historical volume of CO_2 emissions generated in the subcontinent.

During 2000-2010 almost 634 weather and climate extreme events were detected on the Central and South American regions, leaving 16.390 fatalities and 46.643.163 people affected, generating economical losses of the order of USD 208.000.000 (CRED, 2011). The poorest countries were the most vulnerable to the climate hazards. As the impacts of these climate and environmental hazards show that people who are already vulnerable and food insecure are likely to be the first affected. In many regions of Central and South America, agriculture-based livelihood systems that are already vulnerable to food insecurity face immediate risk of increased crop failure, new patterns of pests and diseases, lack of appropriate seeds and planting material, and loss of livestock. People living on the coasts and floodplains and in mountains, drylands, wetlands, and in urban and rural areas are most at risk.

From those events, floods represented 280 episodes, followed by 188 storm and tropical cyclones, and 82 drought events. Colombia, Brazil, Mexico, Haiti, Paraguay, Chile and Panamá were the most affected by floods, while México, Haiti, Jamaica, Dominican Republic and Nicaragua were more affected by storm, and Argentina, Bolivia, Brazil, México, Paraguay and Peru were the most affected by droughts. In 2010 more than 1.800.000 dengue cases were detected in the continent, and Brazil, Colombia, Guatemala, Honduras, Nicaragua, México, Puerto Rico, Dominican Republic and Venezuela were the countries more affected. In 2010 the most common natural disasters that have occurred in the Americas were hydrological (eg. floods), which accounted for 41.2% of the events and meteorological (storms etc), responsible for 36.1% the disaster episodes. The number of victims from hydrological disasters was higher in 2010, compared to the annual average of the last decade (Guha-Shapir, 2011), they were responsible for 34.6% of the disaster victims in the Americas in 2010. The extreme events (storms and floods) observed in northern South America, in November-December 2010, have affected around two million people and killed 246 persons in Colombia and affected 130 thousand people in Venezuela, causing 34 deaths (Rodriguez-Morales, 2011).

The issue of relative vulnerability is critical at this point because it is being used, in combination with socioeconomic indicators, to make decisions that will affect the allocation of financial resources for adaptation. It is thus of more than scientific interest to assess the relative magnitude and consequences of climate impacts in Latin America and the capacity to respond. Vulnerability to climate impacts is thought to reflect both the potential impact and the capacity to respond. The capacity to respond, or adaptive capacity, in itself a subjective notion, is intended to reflect a measure of institutional and economic ability to manage the anticipated impacts. A significant share of the impacts is felt by ecosystems and the damage inflicted is more difficult to evaluate. Although the economic services provided by these systems can be quantified, many of the effects are borne by numerous other species with little or no chance to adapt unassisted to quickly changing environmental conditions.

To visualize these impacts on ecosystems, a multi-disciplinary analysis of current and future impacts of climate and land cover change on ecosystems, water resources, coastal zones, cities and settlements, agriculture, health is made, considering all new information and results from previous studies after the IPCC AR4 was published in 2007. It is useful to discuss the notion of Climate Hotspots as those comprising ecosystems that are particularly affected by the physical consequences of observed climate variability and projected climate change. Focusing on hotspots also helps in defining areas that require urgent attention or need to be highlighted to press for forceful climate action. In this working definition, Climate Hotspots are defined by a combination of factors (World Bank 2009). The changes would imply considerable losses of natural and eventually financial capital. This definition can be applied to some of the system-wide impacts in evidence in the region. These include: a) the bleaching of coral reefs, leading to an anticipated total collapse of the coral biome in the Caribbean Basin; b) the warming and eventual disabling of mountain ecosystems in the Andes; c) the subsidence of vast stretches of wetlands and associated coastal systems in the Gulf of Mexico; and d) the risk of forest dieback in the Amazon Basin

It is necessary to strengthen the resilience of rural people and to help them cope with this additional threat to food security. Particularly in the agriculture sector, climate change adaptation can go hand-in-hand with mitigation. On biodiversity, there is an urgent need to protect to ecosystem services provided by the natural ecosystems that are already vulnerable to recent climate extremes and to possible change in extremes in decades to come. Climate change adaptation and mitigation measures need to be integrated into the overall development approaches and preparation of environmental agendas.

27.1.2. Summary of AR4 + SREX Findings

[to be added in the next version]

27.2. Major Recent Changes in the Region

The continent harbors unique ecosystems and maximum biodiversity and has a variety of eco-climatic gradients and it is rapidly developing; agricultural and beef production is rapidly increasing mostly by expanding agricultural frontiers; accelerated urbanization and demographic changes are remarkable; poverty and inequality is decreasingly continuously, but at a low pace; adaptive capacity is improving related to poverty alleviation. The region has multiple stressors being climate variability and change and land cover change two of the most remarkable drivers of changes.

27.2.1. Climatic Stressors

27.2.1.1. Climate Trends, Interdecadal Variability, and Extremes

In Central and South America, decadal variability and changes in extremes have been affecting large sectors of population, especially those more vulnerable and exposed to climate hazard. Observed changes in rainfall and discharges in Southeastern South America and the Amazon region have been detected a decadal scale, even more important than any unidirectional trend due to land use changes. In the Amazon region, from 2005 to 2011, two major droughts and floods have affected the region, and these changes were linked to natural climate variability rather than to climate change due to deforestation of increase of emission of GHG. Changes in extremes also have been detected in Southeastern South America, in the form of increase in the frequency of number of days with rainfall above 20 to 50 mm, and also increase in the frequency of dry spells in eastern Amazonia and Northeast Brazil, as well as over large regions of Central America.

Many areas in the Intra American Seas region are heavily populated, especially along the coastal zones. A potential **sea-level rise** associated with global warming would be a direct threat to many of the coastal communities (e.g., Lewsey et al. 2004). Severe anomalies in rainfall — both generalized and storm-related — can lead to damaging consequences in the economy, natural environment, and even social unrest in certain parts of the region. On an annual basis, much of the IAS region experiences a dry spell in mid-summer (July and August), which is known as the Mid Summer Drought (MSD). Management of agriculture, water resources, hydropower, and health related issues decisively depends on the timing, severity, and duration of the MSD (also known as *canicula* or *veranillo*). Dust from the Saharan Desert is also present in the Northern Atlantic and the Caribbean (Prospero and Lamb 2003) and it is suspected to influence the regional climate in IAS (Lau and Kim 2007).

Poveda et al (2006) have shown that the El Nin˜o-Southern Oscillation phenomenon (ENSO) is the greatest single cause of interannual variability within the Northern South America and Southern meso American regions, yet its effects are not universal in their timing, sign or magnitude. In addition, some potential impacts of longer run variations within the ocean-atmosphere system of the Atlantic are examined independently and in conjunction with ENSO.

Since 1700, significant interannual and interdecadal variability in the position of the ITCZ has been identified at average periods near 3-7 (ENSO band), 9, 17 and 33 years (Linsley et al. 1994). Over longer time periods, the Caribbean climate changed from dry conditions during the latter part of the Younger Dryas chronozone (10.5- 10 kyr BP) to wetter conditions at the end of the last deglaciation (the early Holocene, approximately 10-7 kyr BP). This wetter climate persisted for nearly 4,000 years before the onset of another dry climate at approximately 3.2 kyr BP, which generally prevailed throughout the late Holocene (Hodell et al. 1991; Lin et al. 1997). Mc Closkey and Keller (2009) analyse hurricane data based on 5000 years old sedimentary records in Belize, including the extreme apparent size of the giant event, and suggest that prehistoric hurricanes were capable of having exerted significant environmental stress in Maya antiquity. More recently, the most extensive drought period in Central America occurred in the 1950s (and was linked to the North American droughts of this time), which is consistent with reported conditions (Liverman, 1999) and with gauge-based precipitation records that show an increasing trend since the early 1960s (Aguilar et al, 2005). In terms of climate extremes, extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of Central America and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras and Guatemala. In 2005, regionally averaged temperatures were the warmest in the western Caribbean for more than 150 years (Eakin et al. 2010) causing the most severe coral bleaching ever recorded in the Caribbean (more than 80% of the corals surveyed were bleached, and at many sites more than 40% died).

In contrast with the widespread warming over the interior of the continent, recent studies have shown a prominent but localized coastal cooling (about -0.25/decade, detected in SST and surface air temperature) during the past 30-50 years extending from central Perú (~15S; Gutierrez et al. 2011a) down to central Chile (~35S; Falvey and Garreaud 2009), presumably in connection with an increase of the upwelling-favourable winds (Narayan et al. 2010). Such cooling trends are not incosistent with a global climate change sceneario. IPCC-AR4 simulations for the 21st century indicate further enhancement of the surface southerly winds along the Chilean coast (Garreaud and Falvey

2009) but a slight weakening off Peru (Goubanova et el. 2010), along with an increase in density stratification at low and subtropical latitudes (Echevin et al. 2011). How these physical changes will impact the biological environment of the ocean represents a major challenge (e.g., Gutierrez et al. 2011b) of particular relevance at local and global scales, as the Humboldt Current system -flowing along the west coast of South America- is the most productive upwelling system of the world in terms of fish productivity.

In the extremely arid northern coast of Chile (18°S-30°S; Schulz et al., 2011), in addition to the long-term precipitation decline during the 20th century, in the mid-70's, the minimum daily temperature increased simultaneously with the change of the Interdecadal Pacific Oscillation from a cold to warm phase. Since this step-like warming, a persistent cooling trend in mean temperature, most evident in the maximum daily temperature regime, was observed associated with a negative trend in the sea surface temperature over a large oceanic region off the coast of northern Chile. Furthermore, the negative trend in rainfall and the decrease in the total cloud cover since the 1970's are likely important factors forcing the coastal vegetation decline in the coastal region north of around 24°S. Southward (from 30ºS to 43ºS, central Chile), a similar negative trend in precipitation is observed over the period 1900 – 2007 (Quintana and Aceituno, 2011). Further south (from 37ºS to 43ºS) the negative trend in rainfall that prevailed since the 1950's, intensified by the end of the 20th century.

In the Andes, ice cores have recorded climate events occurred during the past 1000 years, such as anomalies associated with the Little Ice Age (Vimeux et al., 2009). Observations on glacier extent from Ecuador, Peru and Bolivia give a detailed and unequivocal account of rapid shrinkage of tropical Andean glaciers since the Little Ice Age (Francou et al., 2007; Vuille et al., 2008a, b).

Simultaneously, east of the Andes in Central Argentina (Laguna Mar Chiquita at 30ºS; Piovano et al., 2002), a humid interval was observed during the last quarter of the 20th century, without precedent during the last 240 years of the lake's recorded history. It coincided with the observed regional increase of accumulated precipitation over La Plata Basin and with a negative trend in the number of dry days during the period 1960-2005 for various regions of Argentina (Rivera et al., 2011). Simultaneously, a reduction in the number of droughts is found throughout the century, especially during the warm season (October to March; Barrucand et al., 2007). In general, east and west of the Andes, major changes are observed around mid 1970's.

West of the Andes, in Mantaro Valley (Peru), wet periods mostly occurred in the early 1970's and during the first half of the 1980's (except for the 1993/94 period; Silva et al., 2008), while dry periods occurred mostly during the second half of the 1980's and the 1990's. Consequently, precipitation shows a strong negative trend (-44mm/decade or -6%/decade) since 1976, while temperature records, show a positive trend of 0.10-0.12°C/decade in the maximum temperature for the period 1921-2010, increasing to about 0.23-0.24°C/decade for the period 1976-2010 (Silva and Trasmonte, 2009). However, simultaneously, during the 1960-2002 period, a positive trend of 8 days per decade (1960-2002) in the number of frost days (defined as $T_{min} <= 5ºC$) during the rainy season (September-April) was also observed.

East of the Andes, in La Plata Basin, many works conducted during the EC CLARIS LPB 6th Framework Programme (Boulanger et al., 2010) improved our description and understanding of trends and fluctuations in extreme events in observations and in AR4 20th century simulations. Renom et al. (2011) showed that the circulation patterns associated to cold nights in austral summer changed in mid-1970s characterized by a strong influence of the negative phase Southern Annular Mode (SAM) before 1976. During austral winter, warm nights were more strongly connected to El Niño before than after 1976, a result coherent with a change in ENSO teleconnection patterns after 1976 (Boulanger et al., 2001). The index TN10 (10%-percentile of the minimum temperature) shows the largest significant negative trend for the period 1960–2002 in Uruguay indicating a strong warming of nighttime temperature (Rusticucci and Renom, 2008). In Argentina, changes in the return values of annual temperature extremes after 1976–77 suggest a decrease (resp. increase) in the probability of occurrence of the highest annual maximum (resp. minimum) temperature, leading to a decrease in the annual temperature range (Rusticucci and Tencer. 2008). Interestingly, Rusticucci et al. (2010) showed that the mean number of warm nights is relatively well represented by AR4 climate models. However, no model could adequately represent the maximum of dryness observed over the central Argentinian Andes or the extensive dry season of the Amazon region. In La Plata Basin, observed and simulated trends in warm nights and extreme rainfall were found to be consistent (Marengo et al., 2009a, b, 2011a).

The growth of the river flows in La Plata Basin between 1960 and 1999 was due both to the increased precipitation (Uruguay river), change in ENSO frequency and intensity (Middle Paraguay Basin) and the decreased evaporation attributable to land use change (northern part of the Upper Paranà Basin), including deforestation of natural forest and crop switch from sugarcane and coffee trees to soybean (Doyle and Barros, 2010). Moreover, a faster runoff response to precipitation was observed toward the end of the period and attributed to land cover change (Saurral et el., 2008).

In the Amazon basin, Marengo (2004, 2009) concluded that no systematic unidirectional long-term trends towards drier or wetter conditions in both the northern and southern Amazon have been identified since the 1920s. And that rainfall fluctuations are more characterized by inter-annual scales linked to ENSO or low-frequency variability with a peak at ˜30 years identified in both rainfall and river series in the Amazon. Analyzing a smaller time period and a larger dataset, Espinoza et al (2009a, b) found that mean rainfall in Amazon basin for the 1964–2003 period based on 756 pluviometric stations decreases during the 1975–2003 period (with stronger amplitude after 1982) at an annual rate estimated to be −0.32%. An important aspect detected in rainfall variations in Amazonia is a possible delay on the onset of the rainy season (Butt el al 2011) – or extension of the dry season (Marengo et al 2011b) – that may be a result of land use change. However, the extension of the dry season also exhibits interannual and decadal scale variations linked to natural climate variability.

27.2.1.2. Climate Projections

Projections from global and new experiences using regional models suggest a pattern of rainfall reductions in Eastern Amazonia, Northeast Brazil, central southern Chile, while increases are projected over Southeastern South America and the Northwest Ecuador regions. Increases in dry spells are projected for Central America, Eastern Amazonia and Northeast Brazil, while increases in heavy precipitation are projected over Southeastern South America and western Amazonia. Warming is also projected in Central and South America, and the most intense changes are expected in continental regions, where warming can reach up to 8 C in Amazonia, affecting not only natural and human systems but also glaciers, compromising the supply of water for major cities in South America. These changes are consequence of changes in the regional atmospheric circulation that would affect not only the quality of the rainy season but also the length of the dry season and onset of the rains, especially in the North and South American monsoon regions.

In Central America, the North American Monsoon has been starting increasingly later and has become more erratic in its rainfall, though the intensity of rainfall has been increasing (Englehart and Douglas, 2006). Future climate change scenarios for the 21st century show a weakening of the NAMS through a weakening and poleward expansion of the Hadley cell (Lu et al., 2007).

Respect to future projections derived from global climate models, most studies comparing the amplitude of changes under various emission scenarios in South America (SRES B2, A1B and A2 found very similar patterns with differences mainly in amplitude (Boulanger et al., 2007). For instance, in late 21st century, temperature amplitude changes under A1B (resp. B2) scenario are found to be around 80% (resp. 50%) of those in A2 scenario (Boulanger et al., 2006).

In tropical and subtropical South America, most of the AR4 initial projections were confirmed by further studies. Current climate models are able to reproduce the main features of the seasonal cycle of precipitation during the 20th century. However, they fail in reproducing the observed amounts of mean seasonal precipitation over both tropical and subtropical regions of South America (e.g. Vera et al. 2006; Boulanger et al. 2007; Cavalcanti et al. 2006; Bombardi and Carvalho 2009). Indeed, often overestimating rainfall in NorthWest South America (Boulanger et al., 2007), they are more skillfull in simulating South Eastern South America precipitation annual cycle (Bombardi et al., 2009), extremes (Marengo, 2009) or teleconnections (Vera and Silvestri, 2009). Climate change projections for the A1B scenario in South America show a substantial agreement among IPCC AR4 models in precipitation changes for the period 2070-2099 relative to the period 1970-1999, mainly characterized by an increase of summer precipitation over the northern Andes and SESA (Kitoh et al. 2011), a decrease during the dry season (Kitoh et al., 2011) and with mixed results over the Amazon-SACZ (Vera et al. 2006). Seth et al. (2010) suggest reduced precipitation along the continental SACZ region during austral spring for the A2 scenario, accompanied by a southward shift of the maximum precipitation in the convergence zone. This change is consistent with the alterations on the behavior of the SALLJ for the period 2071-2100 identified by Soares and Marengo (2008).

In the extratropical Andes, late 21st century projections of precipitation suggest a strong reduction of precipitation possibly associated with the positive trend in the Antarctic Oscillation predicted by those models (Quintana and Aceituno, 2011). The same projections also suggest a reduction over central-eastern Brazil during the summer monsoon (Bombardi and Carvalho, 2009). In South Eastern South America, climate change response indicates a possible increase in mean precipitation (Boulanger et al., 2007; Silvestri and Vera, 2009; Seth et al., 2010) and in terms of extreme events like heavy precipitation (Silvestri and Vera, 2009; Marengo et al., 2009c; Sörensson and Menéndez, 2010) and dry spells (Sörensson and Menéndez, 2010) with an increase in the risk of extreme precipitation with a factor of 1.5–2.5 during all seasons. Such an increase in precipitation is associated to increased convergence in Southeast South America throughout the warm season (Seth et al., 2010) in association with a seasonal dipole-like pattern already observed in present observations, potentially associated in the future to an increase of both frequency and intensity of El Niño-like SST conditions in the equatorial central Pacific, and to a Rossby wave train-like anomaly pattern linking the equatorial central Pacific to South America (Junquas et al., 2011).

On rainfall extremes, in western Amazonia, an increase in extreme heavy rainfalls is projected consistent with increasing trends in total rainfall in these regions (Marengo et al., 2009a, b, c). In southern Amazonia, northeastern Brazil and the Amazon basin, the maximum number of consecutive dry days increases, and mean winter and spring precipitation decreases, indicating a longer dry season (Marengo et al., 2009a, b; Sörensson and Menéndez, 2010). Downscaling experiments on climate change scenarios in South America, based on both SRES A2 and B2 emission scenarios for the end of the 21st century, suggest a reduction in Amazonia rainfall and a small increase in SESA rainfall, as well as an increase in dry spells and intense rainfall events in the SAMS/SESA region (Marengo et al. 2009a, b; Nuñez at al. 2008; Soares and Marengo 2008). The projected increase in total and heavy rainfall in SESA, particularly after 2050, is consistent with a projected increase in the frequency of SALLJ events, and with an increase in dry spells. This suggest that future rainfall would be more concentrated on short periods of time followed by longer dry spells, which is in agreement with the findings of Tebaldi et al. (2006). All of these projections suggest potential changes in rainfall extremes in the SESA and SAMS regions. Similarly, Shoigama et al (2011) suggest that although the ensemble mean assessment suggested wetting across most of South America, the observational constraints indicate a higher probability of drying in the Amazon basin (see also Mizuta et al., 2006 and Kamiguchi et al., 2006). Thus, over-reliance on the consensus of models can lead to inappropriate decision making.

Late 21st century A2 projections of mean temperatures suggest increases from more than 4ºC in global climate models (Boulanger et al., 2006) to more than 6º-8ºC in various regional models (Marengo et al., 2009a). In terms of extremes, the number of warm nights (warm minimum temperatures) will also increase, while the number of cold nights will be reduced (Marengo et al., 2009a). In South Eastern South America, the mean temperature increase is closer to 2-4ºC in summer and 3-5ºC in winter (Marengo et al., 2009a, b, 2011c, Chou et al 2011). In terms of extremes, the number of warm nights may increase in A1B scenario by a factor of 4 by the end of the century in the southern extratropics (Menendez and Carril, 2009).

Increased hurricane activity in the tropical Atlantic since the late 1990s, changing fisheries regimes, extreme events, like the 2005 and 2010 and floods in 2009 (Marengo et al 2008, 2011b, c) in the Amazon region and other observed changes in the regions, as well as the need to adapt to time-evolving climate change and increasing temperatures have raised concern among policy and decision makers about climate change in the near term, that is out to 10–30 yr, referred to as the "decadal" time scale (Meehl et al 2009). Impacts resulting from these conditions have significant social, economic, and environmental implications and are consistent with the climate simulations of the twentieth-century and projections of the twenty-first-century climate of some models (See Sention 2.2). Decadal climate predictions aim to cover the gap between seasonal to interannual prediction with lead times of two years or less and projections of climate change a century ahead.

In central and South America, seasonal to interannual prediction, which counts ENSO forecasting as its prime success, relies on the ability of climate models to evolve an initial climate state forward in time to tell us something useful about the state of the climate a season, six months or a year in advance. For these types of prediction, in addition to a good simulation model, an accurate specification of the initial state of the climate is essential. The scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us, and the rate of change as projected exceeds anything seen in nature in the past 10,000 years. Uncertainties remain, however, especially regarding how climate will change at regional and local scales where the signal of natural variability is large. In the regions, decadal-scale predictions will require an increased theoretical understanding: sustained, appropriate observations; advanced assimilation and initialization systems; advanced models (resolution, physics); and estimates of future changes in radiative forcing (Cane et al 2010).

27.2.2. Non-Climatic Stressors

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

Land is facing increasing pressure from competing uses, among them cattle ranching, food production and bioenergy is one. The enhanced competition for land increases the risk of land use changes, which may lead to negative environmental and socio-economic impacts. The higher temperatures and changes in precipitation patterns associated with climate change affect productivity and the process of land degradation, for example, by increasing aridity and the number of dry months per year (thus interfering with the precipitation–evapotranspiration cycle), which has the effect of concentrating precipitation and making it more aggressive. Some of the worst affected areas are on the agricultural frontier in very fragile ecosystems such as the edges of the Amazon forest in Colombia, Ecuador and Peru, where human activities such as deforestation, agriculture, livestock-raising and informal gold mining are causing severe degradation. Land degradation can compromise extensive areas very rapidly.

Land use and land cover change are key drivers of environmental change for the region with significant impacts that increase potential negative impacts from climate change (Sampaio et al., 2007; Lopez and Blanco, 2008). Deforestation rates remain very high in spite of a reducing trend in the last decade (Fearnside, 2008; Ramankutty et al., 2007). Brazil is by far the country in the world with the highest amount of forest loss according to the latest FAO statistics (2010): 2.2 million hectares per year, accounting for 39% of world deforestation for the period 2005-2010. Bolivia and Venezuela also show high areas of deforestation (see Figure 27-1) and these three countries account for 50% of the forest loss in the world. Together, the countries of Central and South America lose a total of 3.8 million hectares of forest per year, corresponding to 69% of the total world deforestation (FAO, 2010).

[INSERT FIGURE 27-1 HERE
Figure 27-1: Area deforested per year for selected countries in Central and South America (2005-2010). Notice three countries listed with a positive change in forest cover (prepared with data from FAO, 2010). Observed rates are: Uruguay 2.79%, Chile 0.23%, Costa Rica 0.90%, Guatemala -1.47%, Nicaragua -2.11%, Honduras -2.16%, Venezuela, -0.61%, Bolivia -0.53%, Brazil, -0.42%).]

According to GLADA project, between 1982 and 2002 additional degraded areas totaled 16.4% of the territory of Paraguay, 15.3% of Peru and 14.2% of Ecuador. If this trend continues, it is estimated that 66.3% of the territory of Paraguay, 62% of Peru and 57.2% of Ecuador will become degraded by the end of the century (ECLAC, 2010b).

The amount of forest loss in Central America is considerably less than in South America, but that is a result of the smaller country sizes; when rates of deforestation are considered, Honduras and Nicaragua show the highest values for the area (Carr et al., 2009). On the other hand, Central America includes three countries where forest cover has recovered in the last years: El Salvador, Costa Rica and Panama; this is mainly the result of socio-economic developments in those countries (Hecht and Saatchi, 2007; Wright and Samaniego, 2008) as well as a strong emphasis on recognizing the environmental services of forest ecosystems (Kaimowitz, 2008). The same positive trend is observed in some South American countries (Figure 27-1) but it is important to note that a substantial amount of forest is gained through plantations which have much lower ecological value than that of natural forests (Izquierdo et al., 2008).

The main cause of the deforestation observed in most of the countries in the area has been widely discussed in the literature: a deliberate development strategy based on the expansion of agriculture to satisfy the growing world demand for food and bio-energy (Müller et al., 2008, Benhin, 2006; Grau and Aide, 2008). This expansion has relied in many cases on government subsidies which have often resulted in lower land productivity and more land speculation (Bulte et al., 2007; Roebeling and Hendrix, 2010).

Two activities have traditionally dominated the agricultural expansion: beef and soy production; but more recently, biomass for biofuel production has become as important (Nepstad and Stickler, 2008). In recent years the expansion of soybean croplands has been increasingly important in the agricultural growth in the region. Soybean-planted area in Amazonian states in Brazil expanded at the rate of 14.1% per year from 1990 to 2005; but this rate is increasing: 12.1% per year during the 1990s (from 1.11 M ha in 1990 to 2.76 M ha in 1999), and 16.8% per year from 2000 to 2005 (Costa et al., 2007). Important changes in land cover have also occurred in other types of forest ecosystems, such as the Chaco dry forests; in NW Argentina (Tucumán and Salta provinces), over the past 35 years 1.4 M ha (some 40% of total) were cleared. Deforestation started in the 1970s as a result of technological changes and increasing rainfall; it continued (with spatial and temporal fluctuations) during the 1980s and 1990s, responding to the sustain global demand of soybean, and was accelerated (to ca. 100,000 ha/yr) during the last years as a consequence of the combination of global (increasing commodity prices), and national economic conditions (Gasparri and Grau, 2009). In central Argentina (northern Córdoba province) approximately 80% of the area that was originally undisturbed forest is now occupied by crops, pastures, and secondary scrub. The main proximate cause of deforestation has been agricultural expansion, soybean cultivation in particular, as a result of the synergistic effect of climatic, socioeconomic, and technological changes (Zak et al, 2008). Even when following good-practice certification schemes, the fast expansion of soy production in South America may result in detrimental impacts for the environment in the region (Tomei, et al 2010).

Over a decade's experience of soybean expansion in South America provides plenty of data that these promises have not only fallen short of fulfillment, but in fact that soybean expansion has contributed directly to increased deforestation, greenhouse gas emissions, landlessness, food insecurity, and rural and urban poverty and vulnerability. A major hope driving the expansion of soy has focused on the potential of agrifuels to help solve the current climate and energy bind. Despite this net energy loss, soy expansion and the conversion of food crops to agrifuel continues worldwide, with European and US businesses turning to Africa and Latin America as the new frontiers for industrial grain production. The correlation between increased agrifuel production, record worldwide food shortages, and increasing social instability is well established (Action 30 Institute, 2009).

The Amazon basin is a key component of the global carbon cycle. Annually, these tropical forests process approximately 18 Pg C through respiration and photosynthesis. This is more than twice the rate of global anthropogenic fossil fuel emissions (Dirzo and Raven 2003). The basin is also the largest global repository of biodiversity and produces about 20% of the world's flow of fresh water into the oceans. Despite the large CO_2 efflux from recent deforestation, the Amazon rainforest ecosystem is still considered to be a net carbon sink of 0.8–1.1 Pg C per year because growth on average exceeds mortality (Phillips et al. 2008). However, current climate trends and human-induced deforestation may be transforming forest structure and behavior (Phillips et al. 2009). Increasing temperatures may accelerate respiration rates and thus carbon emissions from soils (Malhi and Grace 2000). High probabilities for modification in rainfall patterns (Malhi et al. 2008) and prolonged drought stress may lead to reductions in biomass density. Resulting changes in evapo-transpiration and therefore convective precipitation could further accelerate drought conditions and destabilize the tropical ecosystem as a whole, causing a reduction in its biomass carrying capacity or dieback. In turn, changes in the structure of the Amazon and its associated water cycle would have implications for the many endemic species it contains and result in changes at a continental scale.

Land use change studies in southern Brazilian Amazonia (Rodriguez et al 2010) for the last decades showed that the impact on the hydrological response is time lagged at larger scales. The flow paths are clearly affected, depending on basin characteristics such as topography. In general, this change's impacts lead to higher peak streamflows, the

reduction of minimal values and the increment of stormflow. In agreement with previous studies, the detection of signals associated with land use changes was clearly detected at the smallest basin, but proved to be difficult at larger scales, suggesting the existence of non-linear effects, which aggregate across scale compensating small scale effects. Costa el al (2009) show that the climate change due to soybean expansion in Amazonia would be any is manifested in the form or decrease in precipitation after a soybean extension is significantly higher which is when compared to the change after a pastureland extension, a consequence of the very high albedo of the soybean.
With regard to changes in the hydrology of large rivers in South American monsoon region due to change in natural vegetation, Coe et al (2009) observed a discharge increase between 5% and 7.5% at the Madeira, Tapajós and Xingu Rivers based on numerical models. However, observations do not show those projected trends, mainly because of the nonlinear nature of the aggregation of hydrological processes across spatial scales, particularly in heterogeneous landscapes. One of the distinctive features between the hydrological behavior at small and large scales is related to vegetation atmospheric feedbacks. Collini et al (2008) and Saulo et al. (2010) find that Southestern South America precipitation to be more responsive to reductions of soil moisture than to increases. Although feedback mechanisms are present in all scales, the atmosphere influence is more significant at large scales.

Since 1988, the National Institute for Space Studies (Instituto Nacional de Pesquisas Espaciais-INPE), through the PRODES Project (www.inpe.br/prodes) has been monitoring the deforestation rates in the Brazilian Amazonia using remote sensing techniques. LANDSAT images have been processed in such a way that deforested areas above 6.25 ha have been included in the quantification of deforestation rates hectares, in a process that is done once a year. Figure 27-2 shows time series of the deforestation rates from the Brazilian Amazonia, and while large rates were observed during the middle 1990´s and early 2000´s. Rates during 2009 and 2010 are the lowest during the entire record, dropping almost 42% from 2008 to 2009 and about 14% from 2009 to 2010. This may be indicative of the impacts of a series of integrated policies for control illegal deforestation lead by the Ministry of Environment and Federal Police in Brazil Cattle's ranching, infrastructure plans and illegal land appropriation have been pointed out as the major deforestation drivers in the last decade (Alves 2002; Margulis, 2004; Aguiar et al., 2007; Soares Filho et al., 2010).

[INSERT FIGURE 27-2 HERE
Figure 27-2: Deforestation rates in the Brazilian Amazonia (Km2/year) as measured by the PRODES INPE project (www.inpe.br/prodes).]

But forest is not the only important ecosystem threatened in the region. An assessment of threatened ecosystems in South America by Jarvis et al. (2010) concluded that grasslands, savannas and shrublands are under the greatest threat mainly from fires and grazing pressure. An estimation of burned-land in Latin America by Chuvieco et al. (2008) also concluded that proportionally, the most affected ecosystems were the savannas of Colombia and Venezuela. In the Río de la Plata grasslands (central-east Argentina, southern Brazil, and Uruguay), the area covered by grassland decreased from 67.4 to 61.4% between 1985 and 2004. This decrease was associated with an increase in the area of annual crops, mainly soybean, sunflower, wheat, and maize (Baldi and Paruelo, 2008).

Even with technological changes that might result in agricultural intensification, the expansion of pastures and croplands is expected to continue in the coming years (Kaimowitz and Angelsen, 2008; Wassenaar et al., 2007) particularly because of the increasing global demand for food and biofuels (Gregg and Smith, 2010) and because two-thirds of the potential expansion land for cultivation is found in Latin America and Sub-saharan Africa (Nepstad and Stickler, 2008). Enforceable policy and legal reforms will need to be in place to keep this process of large-scale change under control as much as possible, particularly to reduce the impact on poor households who depend directly on the natural resources being depleted (Takasaki, 2007). Indigenous groups require particular attention in this respect. Traditionally, they have been denied the rights to their ancestral lands, but there is a growing acknowledgment that only through recognizing the land ownership and authority of indigenous groups, central governments will be able to succeed in managing many of the natural areas remaining in the region (Larson, 2010; Oltremari and Jackson, 2006). Many indigenous groups are important drivers of land use change in the region but as other human groups, they are mainly looking to improve their living conditions by responding to pressures from a globalized economy (Gray et al., 2008; Killeen et al., 2008).

27.2.2.2. Trends and Projections in Socioeconomic Conditions

Development in the region has persistently displayed three characteristics: low growth rates, high volatility and a very unequal income distribution (*ECLAC, 2008, Barcena 2010*). This combination of factors has generated high and persistent poverty levels. South America has specialized in natural resources (mining, energy, agricultural) which involve direct and intensive use of land and water, and in energy-intensive and, in many cases, highly polluting natural-resource-based manufactures. Meanwhile, Central America has exploited its proximity to the North American market and its relatively low labour costs. In the manufacturing sector, Central American countries have integrated into global value chains mainly at the assembly stage; and, as this stage involves little manufacturing activity as such, the leading industries exporting manufactured products have, in themselves, smaller environmental impacts than those engaging in primary activities. (*ECLAC 2010)*

The financial crisis that broke out in 2008 was transmitted to Latin America through the traditional channel of exports and credit, with a heavy crunch in foreign trade financing. This was manifested in export volumes and prices, remittances and other items directly associated with economic activity. Along with the worsening expectations of consumers and producers, these factors account for the sudden halt to six consecutive years of growth and improving social indicators, representing a contraction in GDP of some 1.9%[1], (-0.2% in case of South America and 0.8% in Central America) in 2009. It was accompanied by a rise in unemployment from 7.5% in 2008 to 8.3% in late 2009, reversing the steady improvements seen in this indicator over a period of five years. All this contributed to higher poverty in 2009, following six years in which it declined by 11 percentage points (from 44% to 33%, which represents 150 million people) while extreme poverty diminished from 19.4% to 12.9% (which represents slightly more than 70 million people), in both cases from 2002 to 2008. In the second half of 2009, industrial output and exports began to recover.

[INSERT FOOTNOTE 1 HERE: Value for all Latin America and the Caribbean.]

South America benefited the most, given the greater relative size of some countries' domestic markets and the greater diversification of their export markets, the orientation of their trade towards raw materials whose prices are rising and the greater share of trade accounted for by China in a number of cases .Conversely, slower growth is expected in more open economies with a less diversified portfolio of trading partners and a greater emphasis on manufacturing trade, this being the case with Central America *(ECLAC 2010)*. Exports of primary products surged in the 2000s, marking up a growth rate four times as high as the rate for the 1990s, and they were particularly strong in the South American. As mentioned earlier, the stronger showing of exports of natural resources stems from the sharp rise in the prices of these subregions' main export products, especially in the case of petroleum, copper, soy, coffee, bananas, iron and steel. The region's performance in exports of manufactures marks a sharp contrast with its showing for primary products, with the growth rate for the former falling sharply from one decade to the next. (ECLAC 2010).

The region is expected to continue to grow in the short term, albeit at a pace that is closer to potential GDP growth, helped by internal demand as credit becomes more available. In South America, this could be boosted by external demand from the Asian economies as they continue to grow at a rapid pace. Beyond the short term, though, the impact could be negative as growth came with unsustainably low real exchange rates. A scenario like the one (with high global liquidity exerting downward pressure on real exchange rates and upward pressure on commodity prices) could lead to overspecialization in the production and export of primary goods. In short, the macroeconomic challenge for the region is to rebuild its capacity to act countercyclically while continuing to create conditions for productive development that is not based solely on commodity exports. (*ECLAC 2010).*

The region also displays high and persistent inequality: most countries have Gini coefficients of between 0.5 and 0.6, whereas the equivalent figures in a group of 24 developed countries vary between under 0.25 and around 0.40. The average per capita income of households in the tenth decile is around 17 times that of the poorest 40% of households. Nevertheless, during the first decade of the century, prior to the financial crisis, the region shows slight but clear trend towards a lesser concentration of income. (*ECLAC 2010)* . Latina American countries also reported gains in terms of human development, although the average annual growth rate has fallen slightly over recent years, In comparative terms, the performance of countries varied greatly (from Chile with 0.878 and Argentina with 0.866

to Guatemala -0.704- and Nicaragua -0.699-) although those with lower relative levels of human development according to this index showed notably higher growth rates than countries with the highest HDI (*UNDP 2010)*

There is also inequality on the supply side of the economy, since modern production structures coexist with large segments of the economy that have lower productivity and income levels and are excluded from technological modernization. Also associated with inequality are disparities in access to water, sanitation and adequate housing for the most vulnerable groups —for example indigenous peoples, Afro-descendants and women living in poverty— and in their exposure to the effects of environmental degradation. The strong heterogeneity of subnational territorial entities in Latin America takes the form of high spatial concentration and persistent inequalities in the territorial distribution of wealth *(ECLAC 2010)*.

The region has a relatively cleaner energy matrix from the standpoint of CO2 emissions, but the region's growing reliance on carbon-based energy options is a cause of concern. The energy matrix also varies strikingly across countries. The trend in emissions from energy sources is in keeping with the trend in energy consumption, which rose at an average annual rate of 2.8% in 1990-2007, thereby surpassing the world average of 1.8% for the same period. The growth rate for energy consumption is, however, higher than the rate of increase in emissions.

The determinants of energy demand, since they are some of the most influential factors in shaping trends in the distribution of energy sources and energy intensity. Econometric estimates5 of energy demand for South America indicate that its per capita income elasticity is generally high (averaging around 1), whereas its price elasticity is quite low (between 0 and -0.2). These estimates also indicate that steady economic growth in the region will be coupled with an upswing in energy demand. In addition, the low price elasticity of energy demand reflects the fact that there are few more energy-efficient technological options available and points to the limitations of a short-term pricing policy as a tool for curbing demand.

The evidence shows that per capita emissions, per capita energy consumption and per capita GDP are closely correlated. It also points to a marginal process of energy decoupling, but one that is not yet strong enough to halt the growth of energy use in Latin America and the Caribbean. Energy emissions projections indicate that, if historical trends in energy and emissions continue along the same trajectory and if the region's economy grows rapidly, then its energy emissions will do so as well. Emissions associated with land-use changes are, on the other hand, diminishing, and an international agreement on this issue could help lead to further reductions (*CEPAL 2010)*.

Latin American faces significant challenges in terms of environmental sustainability, reflecting the specific characteristics of its development: high levels of poverty and inequality among a growing, mostly urban, population that shows increasingly complex migration dynamics; specialization patterns based on primary goods and environmentally sensitive industries, often drawing on static comparative advantages that do nothing to foster the transition towards higher-productivity and higher-value-added sectors; and a significant deficit in infrastructure development. The stakeholders —the State, private sector and civil society— have made progress in incorporating environmental protection into decision-making processes, and particularly in terms of environmental institutions and legislation. Difficulties remain in effectively mainstreaming the environment into sector public policies, however. While the global economic and financial crisis, together with climate change, impose new challenges, they also provide an opportunity to shift development and growth patterns towards a more environmentally friendly economy (*ECLAC 2010*)

27.3. Impacts, Vulnerability, and Adaptation Practices

As compared to the IPCC AR4, and although still not as comprehensive as in Europe or the US, there has been much more scientific documentation on observations of climatic trends, including on extremes, as well as on high resolution future climate change projections, that have allowed various comprehensive studies at national level in some countries of the region on regional impacts of climate change in the near and long term.

27.3.1. Freshwater Resources

South America is the region with the highest average water resources availability. According to the World Bank statistics, water availability in South America is 24,400 m3/cap being the highest of all regions in the world (ref). However, water is poorly distributed in the continent, with areas facing precipitation well over 2,000 mm (Ej. the Valdivian eco-region in Chile, the Amazon headwaters) whereas vast regions face arid or semi arid conditions (Ej. North East Brazil, North of Chile, Coast of Peru, Central Argentina). The main user of water in the region is agriculture accounting for 60% of all withdrawals that are used to fed 18.4 Mha of irrigated land that represent 14% of the world's total cultivated area (ref). The second consumptive user of water is composed by the region's XXX population, of which by 2006 86% has access to water supply (ECLAC, 2010). This means an important improvement in relation to the Milleninum Development Goals (MDG). However, in rural areas the gap is wider, with only 51% of the population having access to those services. On the other hand, while the situation remains quite uneven, the region has made significant progress. Thus, in aggregate terms, the MDG target for 2015 has been achieved. Much remains to be done in terms of service quality, the treatment of urban sewage and the sustainability of services in a scenario of pollution and climate change. Finally, although the period from 1990 to 2005 saw decreases in the numbers of slum dwellers and in the percentage they make up of the region's urban population, over 100 million people in Latin America and the Caribbean are still living in unacceptable conditions (25% of the urban population). In the extreme cases of Bolivia, Nicaragua and Guatemala, the figure easily exceeds 40%. (*ECLAC 2010*)

In terms of non-consumptive use of water, the region distinguishes from having the largest relative contribution of hydropower generation to meet its electricity demand. According to the International Energy Agency (IEA) statistics hydropower covers more than 60% of electricity demand in the region. This is by far the largest share in the world with all other regions (and the world average) falling under a 20% contribution. See Hydropower case study in Section 27.5.1.

Although urban areas in Latin America and the Caribbean (LAC) are not major GHG emitters, they play crucial, yet understudied roles in the climate change arena. They are not only growing sources of greenhouse gases, but (in common with urban settlements in other regions) are also hotspots of vulnerability to floods, heat waves, and other hazards that climate change could be aggravated (Hardoy and Lankao 2011). In Costa Rica, Guswa et al (2007) show results of the analyses from six catchments on the leeward slope indicate that topography exerts a strong control on the importance of orographic precipitation to stream baseflow. In Guatemala, Holder (2006) study fog precipitation that represents a significant proportion of the annual water inputs to cloud forests especially during the dry season. Interception data from this study showed that fog precipitation contributed greater than 7.4% of the hydrological inputs at 2550 m and less than 1% at 2100 m in the Sierra de las Minas. During the dry season fog precipitation contributed 19% of the hydrological inputs to the water budget of the cloud forest. Fog precipitation may be a significant hydrological input to the water resources of the local population. Socio-economic practices such as the conversion of cloud forest to agricultural land may decrease water resources for communities in Guatemala that demand greater quantities of water.

For the coastal region of El Salvador in central America (Aguilar et al 2009) discussed that current climate impacts would be worsened by the combined effect of temperature increases and the occurrence of prolonged dry periods during the rainy season due to climate change. Hydrological dynamics and environmental quality would be negatively affected, especially by the higher probability of recurrence of extremely rainy years and the occurrence of extremely dry years. Evapotranspiration would increase; thus, water availability would not be able to fulfill the needs of humans, animals, or crops.

In the Andean region, enhanced melt is likely to result in short term increase of runoff, but in the long-term changes in runoff may occur which could severely affect the availability of water resources and biodiversity, and as a result glaciers, mountain moorlands *(páramos*, neo-tropical high elevation wetlands*)* and cloud forests in the Andes are experiencing abrupt climate change (Ruiz et al. 2008, Vergara et al, 2011). There is also a well-documented major loss in ice cover and substantial evidence that the associated glacier retreat is accelerating. Casassa et al (2007) show that glaciers in South America have experienced a strong generalized retreat and thinning, especially in recent years, in agreement with the regional and global warming trend. Tropical glaciers in the Andes (those located between

Bolivia and Venezuela) covered an area of over 2,940 km2 in 1970 but declined to 2,758 km2 in 1991 (INRENA 2006) and to 2,493 km2 by 2002 (Kaser 2005). Explaining this generalized retreat there is an upward trend in freezing line height as presented by Bradley et al, (2009). Ruiz et al (2008) show that several peaks in the sierras of Colombia have lost their glacier cover during recent decades (also in Ruiz et al, 2008). Colombian glaciers have lost 50% or more of their area.

Glacier shrinkage has continued to be strong in the last 15 years, with a loss of 10-50% of the glacier area. Chevallier et al (2010) shows that after a period of increased flow due to the glacier melt disequilibrium, the available water resource will decrease along with the rapid shrinking of the glaciers considered as water reservoirs. In Ecuador, the Glacier 15 of Antisana has increased its rate of retreat in the last 10 years as compared to the rates in the period 1956-1993 (Caceres et al., 2006). In the Central Andes, the combination of a secular trends in precipitation reduction and a recent temperature increase are the main causes of the observed current glacier retreats (Le Quesne et al. 2009). The case of the Cordillera Blanca (Peru) is analyzed more in detail with the mid-term (20 years) and long-term (1-2 centuries) impact of the glacier shrinking on the local water resources. In Peru alone, glaciers covered an area of 2,041 km2 in 1970 but had declined nearly 22% to 1,595 km2 by 1997 (INRENA 2006). Precipitation variability is the main driver in the evolution of these glaciers at the interannual scale with temperature having a secondary role (Viulle et al., 2008a, b). Glaciers in this Cordillera feeding the Santa River and afterwards arid conditions have large contributions to overall water availability in different seasons as studied by Kaser et al. (2005) and Mark et al. (2010). In Bolivia, 21 glaciers of the Cordillera Real lost 43% of their volume between 1963 and 2006, essentially over the 1975–2006 period and 48% of their surface area between 1975 and 2006 (Soruco et al., 2009a). Of special relevance (due to the length in the monitoring records) is the fate of the Zongo glacier which has been studied in detail showing a clear retreat of the glacier front (Soruco et al., 2009b; Gallaire et al., 2010).

Glacier retreat diminishes the mountains' water regulation capacity, making it more expensive to supply water for human consumption, power generation, or agriculture, as well as for ecosystem integrity in associated basins. Impacts on economic activities have been monetized (Vergara et al. 2009) and found to represent billions of dollars in losses to the power sector, water supply sectors. Associated risks for the population and consequences for the human activities (tourism, hydropower, agriculture and stock-breeding, large-scale irrigation) are described at each stage of the mountain range. Apparent increase in rainfall variability for some regions implies impacts for many uses, especially for human supply in large cities and for irrigated agriculture. Hydropower is a key energy source for many parts of the region and scenarios of changes of hydrological cycle indicate a complex pattern. See Hydropower case study in Section 27.5.1.

These impacts are of particular relevance in the tropical Andes (Bradley et al., 2006; Viulle et al., 2008b; Mulligan et al, 2010), where based on different AR4 IPCC scenarios for 2050 and 2080, simulations with a tropical glacier–climate model indicate that glaciers will continue to retreat (Vuille et al., 2009). Many smaller, low-lying glaciers are already completely out of equilibrium with current climate and will disappear within a few decades. Poveda and Pineda (2009) shows that as a consequence of global warming, eight tropical glaciers disappeared from the Colombian Andes during the 20th century, and the remaining six have experienced alarming retreat rates during 1987–2007, and assuming such linear loss rate (3 km2 per year), for the near and medium term, the total collapse of the Colombian glaciers can be foreseen by early 2020´s. Juen et al. (2007) showed that future climate scenarios would affect the seasonality of water resources due to temperature increase on the hydrologic process affecting the glaciers of the Cordillera Blanca in Peru. Associated with this same example Mark et al. (2010) explored the vulnerability issues that arise in the Andean communities in association to these projected changes. The Andean communities face a special threat and vulnerability that calls for the need to incorporate with urgency adaptation strategies as those suggested by Young and Lipton (2006).

In inland waters, by 2058, river basins that are impacted by dams or by extensive development will experience greater changes in discharge and water stress than unimpacted, free-flowing rivers. Palmer et al. (2008) showed that dam-impacted basins such as San Juan in Central America and São Francisco and Mearim in South America are likely to need intervention, whereas Parnaiba basin in South America is almost certain. The dam-unimpacted basin of Coppename, in South America, is also likely to require interventions. Despite large decreases in available water in the Amazon, withdrawals will remain low enough to prevent water stress. In addition to changes in annual discharge, an increase in extreme floods and droughts will impact river basins particularly in Argentina. Increased frequency of low-flow conditions in northern Latin America may be extremely important. Glacier melting in the Andes will negatively affect the availability of drinking water, and of water for agriculture and hydropower production (Bradley et al. 2006). Delays in the implementation of proactive forms of restoration, rehabilitation, and river management will inevitably exacerbate the effects of global climate change on efforts to balance the needs of humans and rivers (Palmer et al. 2008).

Vicuña et al (2011) analyze the direct impacts of climate change on the hydrology of the upper watersheds (range in elevation from 1,000 to 5,500 m above sea level) of the snowmelt-driven Limarí river basin, located in north-central Chile (30◦ S, 70◦ W) for the A2, B2 emission scenarios, and projected increase in temperature of about 3–4◦C would accompany a reduction in precipitation of 10–30% with respect to baseline, and annual mean streamflow decreases more than the projected rainfall decrease because a warmer climate also enhances water losses to evapotranspiration. Special attention has been given to the most vulnerable communities in this region (Young et al., 2010), those located today in the transition between the semi arid and arid climates and the need to develop special adaptation tools to face the threats of climate change (Debels et al., 2009). Ospina et al (2009) study the water resource supply-demand relationship in the Sinú-Caribe Basin, Colombia, and point out that projected temperature increases, precipitation increases or decreases and flow reductions shows clearly the adverse effects of global warming on water resources at the local and regional levels in the basin. Nakaegawa and Vergara (2010) show that river discharge in the Magdalena River basin, in Colombia for the 21st century do not change significantly, while precipitation, evaporation, and total runoff into the river show statistically significantly changes over most of the basin.

In a similar fashion as that explained for the tropical Andes, glaciers and icefields in the Central-South Andes in Chile and Argentina also face significant reductions as presented by different authors (Masiokas et al., 2008; Leiva et al., 2007; Chen et al., 2007; LeQuesne et al., 2009; Barcaza et al., 2009; Nicholson et al., 2009; Bown et al., 2008; Strelin and Iturraspe, 2007; Bown and Rivera, 2007; Schneider et al., 2007). In this region the effect of glacier retreat is compounded with changes in snowpack extent (Lopez et al., 2008; Masiokas et al., 2006) magnifying changes in hydrograph seasonality reducing flows in dry seasons and increasing it in wet seasons (Pasquini et al., 2008; Vich et al., 2007; Casassa et al., 2009; Pellicciotti et al., 2007; Masiokas et al., 2010).

Gradual changes in glacier and snowpack have impacts in the availability of water resources when in moments when their contribution is most critical (dry seasons or dry years). In the future, with climate change exacerbating these changes it is also plausible to conceive the occurrence of extreme impacts. Examples of these type of impacts are the Glacial-lake outburst floods (GLOFs) occurring in the icefields of Patagonia (Dousaillant et al., 2010) or volcanic collapse and debris flow associated with accelerated glacial melting in some volcanoes in south Chile and Argentina (Tormey, 2010).

Aside from changes in the accumulation of ice and snow, the Central-South Chile and Argentina region also faces a trend in reduction in precipitation that is projected to continue into the future. A trend analysis of the Puelo River a watershed located in the Valdivian eco-region in Chile and shared with Argentina show a general decreasing trend in the 1943-1999 period with serious ecological and economic implications for the future (Lara et al., 2008). A similar situation occurs to the closely located in Argentina Limay basin where recent trends and future scenarios show a reduction in flows (especially low flows) compromising hydropower generation (Seoane and Lopez, 2007). Chile's main hydroelectric basins could also be affected by this reduction in annual average flow and changes in seasonality (ECLAC, 2009; Stehr et al., 2010). In the semiarid regions of Central Chile-Argentina these reductions in flow could have significant effects on already vulnerable regions which hold large populations (city of Santiago for example) and extensive agriculture irrigation demands (ECLAC, 2009; Souvignet et al., 2010).

East of the Andes in southern South America, streamflow trend analysis done by Pasquini et al. (2006), Troin et al., (2010) in the Laguna Mar Chiquita, a closed lake in central Argentina, show an increase in runoff associated with an increase in precipitation. This increase in runoff could affect rates of erosion which are critical especially in lowflow lands in those streams draining to the Atlantic Ocean (Rodrigues Capitulo et al., 2010). South from these basins in the Argeninan Patagonia there is not such a clear trend with the exception of the Rio Negro with a positive trend in annual discharge (Pasquini et al., 2007). The Santa Cruz basin presents a positive trend in discharge in spring time possibly associated to snowmelt trend of the Patagonia icefields a similar effect to what was explored in for the Central Argentina-Chile region.

The Rio de la Plata drainage basin, with an area of approximately 3 million km^2 and annual mean discharge of 21,500 m^3/s, is one of the largest runoff nets in South America, second only to the Amazon River. It covers almost the total continental width at 21ºS. The main contributions to the Rio de la Plata basin come from the Parana, Paraguay and Uruguay Rivers (Pasquini and Depetris, 2007). There have several studies that have shown a positive trend in streamflow in the Rio de la Plata basin (Pasquini and Depetris, 2007; Doyle and Barros, 2010; Krepper et al., 2008; Conway and Mahe, 2009; Saurral et al, 2008; Dai et al., 2009). Two are the factors that have been associated with this increase in runoff: on one hand there is an increase in precipitation in the region but also there is a land use change trend that has reduced evapotranspiration in the basin (Doyle and Barros, 2010; Saurral et al, 2008). According to Doyle and Barros (2010) the precipitation increase factor has been more important in the southern basins whereas the land use change factor has been more important in the northern ones. Projections for the future show that this trend should continue. Nohara et al., (2006) show that in average for a series of climate models the Parana river would experience almost a 5% increase runoff in the future as compared to historic conditions.

In the Amazon region, At seasonal time scales, Marengo et al (2011b), Lewis et al (2011) and Espinoza et al (2011b) found that during the austral spring and winter of 2010, the most severe drought since the beginning of the XX Century can be explained by the combination of a El Niño event in austral summer and a very warm episode in the Atlantic in boreal sprint and summer that accumulated their effects. This was the case of droughts as in 1983 and 1998 and most recently in 2010. However, one of the most intense droughts in western Amazonia in 2005 was mainly due to an anomalously warm tropical North Atlantic Ocean (Marengo et al 2008a, b, 2011a, Cox et al 2008, Zeng et al 2008, Samanta et al 2010, and Tomasella et al (2010). In contrast, the extreme floods in Amazonia during 2009 were due to an anomalously warm tropical South Atlantic Ocean (Marengo et al 2011c). In the present, intense fires were detected during the droughts of Amazonia in 2005 and 2010, accompanied by an extension of the dry season and late onsets of the rainy season observed during the last 50 years or so (Marengo et al 2008, 11b). This tendency was not observed during the wet years of 2009 in Amazonia (Marengo et al 2011 a). On longer time scales, Marengo (2004, 2009) and Satyamurty et al (2009) concluded that no systematic unidirectional long-term trends towards drier or wetter conditions in both the northern and southern Amazon have been identified since the 1920s, but that a clear indication of decadal scale variability, with shifts in the middle 1940´s and 1970´s were detected in rainfall and river records in Amazonia. Espinoza et al. (2009c) showed that for the 1974-2004 period an apparent stability in mean discharge at the main stem of the Amazon in Obidos is explained by opposing regional features that principally involve Andean rivers.

The Amazon Andean rivers hold a significant not completely developed hydropower resources. In the Ecuador Andes, projections for the Paute basin (Buytaert et al., 2009; Buytaert et al., 2010; PACC, 2009) which holds the largest proportion of hydroelectricity capacity in the country, indicate in average an increase in runoff and hence a potential increase in generation capacity. In Bolivia in the Alto Beni region Fry et al. (2010) projected on the other hand that climate change could affect aquifer recharge and associated agriculture activities. Adding to this uncertainty in trend analysis of the Amazon River is the significant influence that deforestation has in river discharge as explored by Coe et al. (2009). In terms of future conditions, land use change could also play a significant role on future streamflow trends. Considering climate scenarios Nohara et al. (2006) showed that on average there could be an increase in future runoff in the order of 5%. This figure is equivalent to that found by Aerts et al. (2006) but differs from an almost 20% reduction projected by Palmer et al. (2008).

Semi-arid regions are characterized by a high vulnerability of natural resources to climate change, pronounced climatic variability and often by water scarcity and related social stress (Krol and Bronstert, 2007). As presented previously North Central Chile and Argentina presented a clear example of this type of vulnerability. Another semi-arid region that has been studied thoroughly in this regards is the Brazilian North East region. De Mello et al. (2008), Gondim et al. (2008), Souza et al. (2008) and Montenegro and Ragab (2010) all showed in different basins in the region that future climate change scenarios would impact water availability for agriculture irrigation needs due to projected reductions in precipitation and increases in evapotranspiration demands. Following similar projections Krol and Bronstert (2007) and Krol et al. (2006) presented an integrated modeling work that linked projected impacts on water availability for agriculture to economic impacts that could potentially drive full scale migrations in the Brazilian northeast region. The level of vulnerability associated to actual and future conditions in this region have motivated the study of a series of adaptation measures and policies. Broad et al. (2007) and Sankarasubramanian et al. (2009) for example studied the potential benefits of streamflow forecast as a way to reduce the impacts of climate change and climate variability on water distribution under stress conditions. Another type of adaptation measure affecting agriculture water demand is increased efficiency as explored by Montenegro et al. (2010) and Bell et al. (2010). The role of groundwater pumping as an adaptation measure in semi-arid regions has also being explored for the Brazil northeast region by Döll (2009), Kundzewicz and Döll (2009) and Zagonari (2010). An effective implementation of most of these adaptation measures require the correct level of adaptation capacity through a right combination of governance and institutions (Lemos, 2008; Engle and Lemos, 2010; Zagonari, 2010; Halsnaes and Verhagen, 2007).

Studies of climate change impacts on water resources in northernmost countries in South America are not as abundant as in other regions already assessed. Ospina et al (2009) study the water resource supply-demand relationship in the Sinú-Caribe Basin, Colombia, and point out that projected temperature increases, precipitation increases or decreases and flow reductions shows clearly the adverse effects of global warming on water resources at the local and regional levels in the basin. Nakaegawa and Vergara (2010) show that river discharge in the Magdalena River basin, in Colombia for the 21st century do not change significantly, while precipitation, evaporation, and total runoff into the river show statistically significantly changes over most of the basin. Coincidently with these results Dai et al (2009) showed that for the Magdalena basin in Colombia and Orinoco basin in Venezuela there are no significant trends.

Another region that lacks of peer reviewed literature is Central America. Most available works cover the Mesoamerican region of the continent where projections show a drier future with implications to agriculture and hydropower generation sustainability. Maurer et al (2009) studied climate change projections for the Lempa basin, the largest basin in Central America, covering portions of Guatemala, Honduras and El Salvador. Through an uncertainty based approach Maurer et al. (2009) showed that future climate projections imply a reduction in the order of 20% in inflows to major reservoirs in this system. This could have large hydropower generation implications as discussed more thoroughly in Case Study 8.1. The social and economical implications of these drier scenarios for the agricultural sector have been studied by Benegas et al. (2009) and Manuel Navarrete et al. (2007). Adaptation strategies are suggested in both works.

27.3.2. Terrestrial and Inland Water Systems

The highest percentage of rapidly declining amphibian species occurs in Central and South America. Brazil is among the countries with the most threatened bird and mammal species. Plant species are also rapidly declining in Central and South America, Central and West Africa, and Southeast Asia (Bradshaw et al. 2009). Climate change should further enhance species decline, as in the case of vertebrate fauna to which 80% of the climate projections based on a relatively low greenhouse-gas emissions scenario result in the local loss of at least 10% of the vertebrate fauna over much of North and South America (Lawler et al. 2009). Largest changes are predicted for Central America, and the Andes Mountains where, assuming no dispersal constraints, specific areas are likely to experience over 90% turnover, so that faunal distributions in the future will bear little resemblance to those of today (Lawler et al. 2009). In Brazil, projections for Atlantic forest birds (Anciães & Peterson 2006) and endemic bird species (Marini et al. 2009), bats (Machado & Aguiar 2010) and plant species (Siqueira & Peterson 2003) of the cerrado (savannas of central Brazil) indicate that adequate environmental conditions for occurrence will dislocate towards south and southeast, precisely where fragmentation and habitat loss are worse. Elevational specialists, i.e. a small proportion of species with small geographic ranges restricted to high mountains, are most frequent in the Americas (e.g. Andes) and might be particularly vulnerable to global warming because of their small geographic ranges and high energetic and area requirements, particularly birds and mammals (Laurance et al. 2011).

Estimates of risk of plant species extinction in the Amazon, that do not take into account possible climate change impacts, range from 5-9% by 2050 with a habitat reduction of 12-24% (Feeley & Silman 2009) to 33% by 2030 (Hubbell et al. 2008).

Among the components of aquatic biodiversity, fish are the best known organisms (Abell et al. 2008) and Brazil has the richest icthyofauna of the planet (Nogueira et al. 2010). For instance, the 540 Brazilian small microbasins host 819 fish species with restrict distribution. However, 29% of these microbasins lost more than 70% of its natural vegetation cover and only 26% have significant overlap with protected areas or indigenous reserves. Moreover, 40% of the microbasins overlap with hydrodams or have few protected areas and high rates of habitat loss (Nogueira et al. 2010).

Changes in the regional South American climate—either caused by rising greenhouse gases or by local deforestation—may cause some parts of the Amazon rainforest to cross an ecological tipping point during this century (Cox et al. 2000; Lenton et al. 2008; Nobre and Borma 2009, Sampaio et al 2007, Salazar et al 2007). Here, 'tipping point' refers to a critical threshold at which a relatively small perturbation can qualitatively alter the state or development of a system (Lenton et al. 2008). In Amazonia, scientists have suggested that the tipping point is represented by some threshold in the area of the rainforest that, if crossed, would lead to a reduction of the rainfall and to an extension of the dry season, causing further reduction of the rainforest and shifting the system into a new and drier equilibrium. For instance, Amazon and Cerrado deforestation is found to contribute to an increase of the duration of the dry season in this region (Costa and Pires, 2009) associated to an increase in near-surface air temperature and a decrease in evapo-transpiration and precipitation. Such conditions in Eastern Amazonia (Malhi et al., 2008) will lead to stronger water-stress, which may actually be more appropriate for seasonal forest (more resilient) than for savanna, although seasonal forests are more vulnerable to fires, which risk may increase under climate change conditions, possibly triggering the transition of these seasonal forests into fire-dominated, low biomass forests, with the risk of reaching a ''tipping point'' beyond which extensive rainforest would become unsustainable (Justino et al 2010, Mahli et al 2008). In fact, Pueyo et al (2010) found evidence of a critical transition to a megafire regime under extreme drought in rainforests; this phenomenon is likely to determine the time scale of a possible loss of Amazonian rainforest caused by climate change. At a larger scale,
Kirilenko and Sedio (2007) suggest a positive feedback between deforestation, forest fragmentation, wildfire, and increased frequency of droughts appear to exist in the Amazon basin, so that a warmer and drier regional climate may trigger massive deforestation.

Some model projections (Betts et al. 2004; Cox et al. 2004; Salazar et al 2007; Sampaio et al. 2007; and Sitch et al. 2008) exhibit over the next several decades a risk of an abrupt and irreversible replacement of Amazon forests by savanna-like vegetation, with possible large-scale impacts on climate, biodiversity and people in the region. This process is referred to as the "die-back" of the Amazon, and is simulated by few climate models. After reaching a "tipping point" in climate (CO2 concentration, air temperature) the forest stops behaving as a carbon sink and becomes a carbon source. After that, the forest enters a state of collapse and is then replaced by savanna-type vegetation in a process that has been referred to as the "savannization" of the Amazon region. Loss of the Amazon either in the short term through direct deforestation or in the long term through climate change could have widespread impacts, some of which have the potential to exacerbate the changes in climate or in forest cover in a positive feedback loop. Furthermore, these two drivers of change in forest cover are unlikely to act independently of one another. The resilience of the forest to the combined pressures of deforestation and climate change is therefore of great concern, especially since some major climate models predict a severe drying of Amazonia in the 21st century (Betts et al 2008; Malhi et al 2008, 2009; Nobre and Borma 2009, Marengo et al 2011b). The likelihood of this die-back scenario occurring, however, is still an open issue and the uncertainties are still very high (Shiogama et al 2011).

In the Amazon region, Lapola et al (2011) make a first attempt to assess these impacts of climate change through a systemic approach, using a spatially explicit modeling framework to project crop yield and land-use/land-cover changes by 2050. The results show that, without any adaptation, climate change may exert a critical impact on the yields of crops commonly cultivated in the Amazon (e.g., soybean yields are reduced by 44% in the worst-case scenario). Putting an end to deforestation in the Brazilian Amazon forest by 2020 (and of the Cerrado by 2025) would require either a reduction of 26%–40% in livestock production until 2050 or a doubling of average livestock density from 0.74 to 1.46 head per hectare. These results suggest that (i) climate change can affect land use in ways not previously explored, such as the reduction of yields entailing further deforestation, and (ii) there is a need for an integrated/multidisciplinary plan for adaptation to climate change in the Amazon.

27.3.3. Coastal Systems and Low-Lying Areas

27.3.3.1. The Mesoamerican Reef

An analysis (Vergara et al 2009) indicates that were extreme sea surface temperatures to continue, it is possible that the Mesoamerican coral reef will collapse by mid-century, causing billions of dollars in losses. Thus, while one-third of the more than 700 species of reef-building corals worldwide are already threatened with extinction (Carpenter et al. 2008), it is estimated that 60 to 70 endemic species of corals in the Caribbean are also in danger

Extreme high sea surface temperatures have been increasingly documented in the western Caribbean near the coast of Central America and have resulted in frequent bleaching events (1993, 1998, 2005, and again in 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras and Guatemala). In 2005, regionally averaged temperatures were the warmest in the western Caribbean for more than 150 years (Eakin et al 2010). These extremes temperatures caused the most severe coral bleaching ever recorded in the Caribbean: more than 80% of the corals surveyed were bleached, and at many sites more than 40% died. Recovery from such large scale coral mortality will depend on the extent to which coral reef health has been compromised and the frequency and severity of subsequent stresses to the system. More than one bleaching event over a short timeframe can be devastating. An analysis (Vergara et al 2009) indicates that were extreme sea surface temperatures to continue, it is possible that the Mesoamerican coral reef will collapse by mid-century, due to high sea surface temperature anomalies, causing billions of dollars in losses.

In the wake of coral collapse, major economic impacts on fisheries, tourism, and coastal protection are anticipated, as well as severe loss of biodiversity, species extinction and impacts on ecosystem integrity. Appropriate monetization of these impacts is not easy. Among these, the loss of species and ecosystem integrity is much more difficult to evaluate, yet may represent the most important. One-third of the more than 700 species of reef-building corals worldwide are already threatened with extinction (Carpenter et al. 2008). It is estimated that between 60 to 70 endemic species of corals in the Caribbean are also in danger. The cost of reducing vulnerability of corals to bleaching and accelerating recovery of affected populations are likely to be very high but they remain to be assessed.

The Mesoamerican Reef (MAR) stretches over 1,000 km and includes Western Hemisphere's longest barrier reef in Belize, as well as fringing reefs off Mexico's Yucatan Peninsula, along the mainland coasts of Guatemala and Honduras as well as around the Bay Islands, Honduras. These vast reef complexes and neighboring seagrass meadows, deep and shallow lagoons, and mangrove forests, form a dynamic mosaic of marine biodiversity. The overall ecoregion covers approximately 464,419 km^2, with 192,648 km^2 in watersheds and 271,771 km^2 in diverse marine habitats (HRI, 2010). In Belize alone, the reef and mangrove ecosystems were estimated to contribute approximately \$395 - \$559 million US dollars in goods and services each year, primarily through marine-based tourism, fisheries and coastal protection (Cooper *et al.*, 2008).

A few decades ago the Mesoamerican reef was considered to be in better condition than most other reefs of the Caribbean —but this distinction is now uncertain. Many of the reef health indicators (particularly for fish abundances) are now in poor condition (HRI, 2010). The 2010 Report Card for the Mesoamerican Reef found that only 1% of reefs are in very good' condition, 8% are 'good', 21% are 'fair", 40% 'poor', and an alarming 30% of reefs are now in 'critical' condition (HRI, 2010). The results are based on 130 reefs surveyed (from Mexico Belize and Honduras) and evaluated with four indicators of reef health (coral cover, fleshy macroalgal cover, herbivorous fish biomass and commercial fish biomass) that are compared to a regionally standardized ranking criterion for each indicator (HRI, 2010).

There are many reasons for the decline in reef health occurring at the local, regional and global levels. The four long-recognized main threats (over-fishing, coastal development, inland land clearing and agriculture, and climate change) continue with growing intensity and are now joined by the new threats of invasive lionfish – now found virtually everywhere in the MAR, and offshore oil drilling (HRI, 2010).

Despite the virtual laundry list of threats, climate change is viewed a significant factor in the current decline of corals, in particular. The long term effects of coral bleaching and ocean acidification are difficult to measure, but mounting evidence is indicative of lasting impacts.

The Mesoamerican Reef experienced its first widespread documented bleaching event in 1995 (McField, 1999), followed by the more severe and widespread bleaching event in 1998 and a less severe but also widespread event in 2005 (McField *et al*., 2008). The impact of the 1998 bleaching event was unprecedented in the past century, based on measured reduction in skeletal growth rates in the dominant reef builder, massive *Montastraea faveolata* corals, over the past 75–150 years from the Mesoamerican Reef (Carilli *et al*.,2009). Similar long-term reductions in coral growth rates have been recorded in Panama (Guzman et al., 2008).

A new question has recently emerged, as to whether or not shifts in *Symbiodinium* clade membership may affect the long-term geochemical record contained in coral skeletons. Carilli *et al*. (in review) found a significant baseline shift in $d^{18}O$ anomalies without an equivalent change in $d^{13}C$ after known bleaching events, indicating that *Symbiodinium* clade plays an important role in the geochemistry of the coral skeleton, resulting in a shift in skeletal oxygen isotopic composition after coral bleaching (the loss and potential exchange of symbionts). Interestingly, the cores that record this shift in $d^{18}O$ isotopic values after the bleaching event originated from the two sites that showed quick recovery in coral skeletal growth rates after the bleaching event, possibly denoting a measurable adaptive response (Carilli *et al*., 2009).

In addition to the stress of rising water temperatures, as atmospheric carbon dioxide becomes dissolved in seawater it causes a reduction in pH that requires most calcifying organisms to expend additional energy for calcification under lower pH. A recent laboratory study found that crustose coralline algae (important for cementing the reef and facilitating the settlement of coral recruits) and some corals were also more affected by bleaching under higher CO_2 (Anthony *et al*., 2009). No widespread *in situ* measurements of pH and carbonate saturation state are known to have occurred in the MAR in the last decade, and such are needed to establish actual chemical shifts that may be occurring.

Significant financial and human resources are expended annually in the MAR to support reef management efforts. These actions, including the creation of marine reserves to protect from overfishing, improvement of watershed management, and protection or replanting of coastal mangroves, are proven tools to improve ecosystem functioning. However, they may also actually increase the thermal tolerance of corals to bleaching stress and thus the associated likelihood of surviving future warming (Carilli *et al.,* 2009).

One innovative adaptation program underway in Belize involves the propagation of two species (*Acropora palmata* and *A. cervicornis*) that were formally the most common corals in Belize and the Caribbean. Their abundance has been reduced by over 98% Caribbean-wide, due to climate-related impacts, including bleaching, disease and hurricane damage, in just a few decades. These endangered are now being grown in six “nursery” areas where clippings (over 3000 to date) are being replanted on the reef (Carne 2011, in preparation). Seventeen distinct genotypes have been identified and are being monitored thru bleaching events to help identify bleaching-resistant genotypes for further propagation (Carne, L. 2011).

Despite the commendable management efforts underway within the region, including: the regions network of over 30 marine and 30 coastal protected areas; Belize's full protection of all parrotfish and surgeonfish in 2009, and Honduras' full protection of all sharks in 2010; all of these reef management efforts may be overshadowed by the cumulative effects of global climate change is serious carbon dioxide reductions are not achieved.

27.3.3.2. Climate Change Impacts on Mangroves Ecosystems

Mangroves are affected by a multi-level multi-layered anthropogenic constraints and are sensitive to many climate-driven disturbances**.** The impact of pollution generated by poorly controlled industrial processes, deforestation and conversion lands, interacting with coastal dynamics are increasing the speed of the sedimentation and a significant loss of mangrove areas in many coastal and low lying areas from Central and South America. In Colombia (Lampis

2008) reports that mangroves have been severely affected presenting a rate of survival of original mangroves areas between 12.8% and 47.6% in the Tumaco bay. The net result is the collapse of the mangrove ecosystem and the virtual extension of the fisheries. The impact on the livelihoods of the many families of fishermen has been dramatic, compelling them to displace their fishing activities outside the bay where they cannot compete.

One of the most important factors determining the dynamics of mangroves is relative sea-level change. In order to cope with rising sea level, rates of sedimentary vertical accretion and subsurface accumulation of organic materials should equal rates of sea-level rise; otherwise mangroves would experience erosion of their substrate, inundation stress, increased salinity, and eventually their disappearance. Gatriot el al. (2009) using satellite images of South American mangrove-colonized mud banks suggests the dominant control of ocean forcing by the 18.6 year nodal tidal cycle expecting during the coming decade, an increase of mean high water levels of 6 cm along the coast of French Guiana which will lead to a 90m shoreline retreat**.** The net result will be the flooding of thousands of hectares of mangrove forest and a shoreline retreat of 100–300 m. The authors point out also that there are other forcing mechanisms, namely the nodal cycle, sea-level rise by global warming, the El Niño Southern and the Amazon sedimentary discharge fluctuations, interact to modulate the mean high water level (MHWL) of this low lying coast, defining the net substrate for mangroves settlement.

Caribbean mangroves are being deforested at a faster rate than rainforests, yet their protective role against hurricane damage extends not only shoreward to coastal environments but also seaward to increasing the resilience of offshore coral reefs. Mumby and Hastings (2008) by modeling the consequences of ontogenetic reef fish dispersal between Caribbean mangroves and adjacent coral reefs, quantified the broader implications of ecosystem connectivity for ecosystem function and resilience to climate-driven disturbance. Specifically, ontogenetic mechanisms of ecosystem connectivity involving parrotfish *Scarus guacamaia* may increase the probability that coral populations will recover from climate-induced changes in hurricane disturbance. This largest herbivorous fish in the Atlantic, was found to have a functional dependence on mangroves and its distribution was confined to shallow reefs neighboring mangroves. Efforts to arrest mangrove deforestation and restore mangrove habitats are likely to increase the likelihood of recovery of corals on mid-depth (7–15 m) reefs after disturbance.

The Caribbean region is an important reservoir of mangrove peat able to maintain a mangrove habitat despite changing Holocene sea levels, but also, this peat-forming mangrove systems are particularly vulnerable to human interference. Works from Wooler et al. (2007) and McKee et al. (2007) shows that during the earlier part of the Holocene, mangroves from Belize cays were able to keep pace with a relatively rapid rise in sea level, suggesting that the mangroves were able to take advantage of varying proportions of precipitation versus seawater during the Holocene, which likely came about as the rate of sea-level rise changed. Also, the McKee at el. (2007) study findings found another important mechanism - the subsurface accumulation of refractory mangrove roots- that allow mangroves common to the Caribbean region to adjust to changing sea level, having relevance for predicting the effects of sea-level rise and biophysical processes on tropical mangrove ecosystems. Their removal would stop soil accretion, while decomposition, physical compaction and erosion processes continue, ultimately leading to submergence and land loss. Although mangrove systems at Twin Cays and other Caribbean locations have persisted for thousands of years, their continued existence depends on future rates of relative SLR. To avoid submergence, vertical building of these mangroves must equal relative SLR (eustatic rise plus local subsidence).

New palynological information on the dynamics of the Bahia Honda mangrove from the eastern coast of San Andres Island (Colombia) in the southwestern Caribbean for the late Holocene show the combined effects of natural events (strong storms and sea level rise), and human disturbances (Gonzalez et al. 2010). A storm (most probably a hurricane) was recorded around ad 1600, caused sediment reworking and the subsequent loss of about 2000 years of the vegetation record. Mangroves and coastal vegetation started to recover at ad 1700, reaching their maximum extent within a few decades, when microforaminifera shells became abundant thus suggesting a relative sea-level rise. Mangrove and coastal vegetation declined sharply as a consequence of the establishment of coconut plantations around ad 1850. The recovery of the mangroves after ad 1960 is a result of the combined effect of relative sea-level rise and drastic changes in the local economy from coconut plantations to commerce.

Data compiled by IPCC (2007, chapter??) report that during the last century global sea level rose at a rate of about 1.7 mm/yr, with a notable increment of up to 3 mm/yr during the last decade. Contrastingly, the evaluation of stratigraphic sequences and direct measurements on mangroves have shown a highly variable natural range of sedimentation rates, i.e. 0.8–6 mm/yr which depends on natural rates of sediment supply and erosion. Therefore, the assessment of natural recovery processes of individual mangrove types is crucial for the understanding of their survival ability under future scenarios, which project accelerated sea-level rise rates between 0.18 mm/yr and 13 mm/yr for the next century. Despite the growing interest on the effects of sea-level rise on shorelines and coastal ecosystems, studies on long term dynamics of Caribbean mangroves are still scarce. Further knowledge on the availability of suitable coastal areas, the amount and seasonality of fresh water and sediment supply, the proximity of neighboring mangrove areas, and the disturbance history are required in order to understand the long-term dynamics of particular mangrove areas and to predict their ability to cope with climate change.

Peru and Colombia are two of the eight most vulnerable countries to potential climate change impacts on their capture fisheries. This vulnerability is related to the combined effect of observed and projected warming, the relative importance of fisheries to national economies and diets, and limited societal capacity to adapt to potential impacts and opportunities. In addition to the effects of climate change, fisheries production systems are already under considerable stress from overfishing, habitat loss, pollution, invasive species, water abstraction and damming (Allison et al., 2009). Peru experiences recurrent ENSO events during which the Peruvian bay scallop (*Argopecten purpuratus*) undergoes substantial changes in its stock size. According to Badjeck et al. (2009), formal institutions are slow to learn, self-reorganize and respond to climate variability while fishermen's responses are spontaneous, ensuring a rapid process of individual adaptation. Institutional responses are mostly ex-post, and are not strongly shaped by past experience, thus eroding the resilience of the system. However, fishermen's responses sometimes lead to negative outcomes such as local stock overexploitation or 'invasion' of natural scallop habitats for scallop grow-out, and formal institutions play an important role in resilience building through the control of effort and entry in the fishery. Individual adaptation, a feature of resilience, is occurring and will occur spontaneously, changing property right regimes and responding not only to climate variability but also market forces. In order to maintain and build resilience and engender positive management outcomes, formal institutions not only need to shape fishermen decision-making, they must also contribute to knowledge building as well as the adoption of innovative approaches.

In contrast with the widespread warming over the interior of the continent, recent studies have shown a prominent but localized coastal cooling (about -0.25/decade, detected in SST and surface air temperature) during the past 30-50 years extending from central Perú (~15S; Gutierrez et al. 2011a) down to central Chile (~35S; Falvey and Garreaud 2009), presumably in connection with an increase of the upwelling-favourable winds (Narayan et al. 2010). Such cooling trends are not incosistent with a global climate change sceneario. IPCC-AR4 simulations for the 21st century indicate further enhancement of the surface southerly winds along the Chilean coast (Garreaud and Falvey 2009) but a slight weakening off Peru (Goubanova et el. 2010), along with an increase in density stratification at low and subtropical latitudes (Echevin et al. 2011). How these physical changes will impact the biological environment of the ocean represents a major challenge (e.g., Gutierrez et al. 2011b) of particular relevance at local and global scales, as the Humboldt Current system -flowing along the west coast of South America- is the most productive upwelling system of the world in terms of fish productivity.

27.3.4. Food Production Systems and Food Security

In Central and South America agro-ecosystems are being affected in isolation and synergistically by climate variability and extremes and land use change, since these are comparable drivers of environmental change. It is predicted that a great part of the increased global demand in food and biofuels will be supported by countries in South America and Africa, which possess the largest proportions of potential arable land, accounting for more than 40% of the global total (Zhang and Cai, 2011). In the future our region will face both, the great challenge of fulfilling the growing food and biofuels demand and the impact of climate change, trying to preserve natural resources through sustainable development options. Although optimal land management could combine efficient agricultural and biofuels production with ecosystem preservation under climate change conditions, current practices are far from optimal, leading to a deterioration of ecosystems throughout the continent (Lal 2009). Certainly, soybean expansion in South America, forced by international demand, has contributed to this deterioration by increased deforestation, greenhouse gas emissions, landlessness, food insecurity, and rural and urban poverty and vulnerability (Action 30 Institute, 2009).

27.3.4.1. Observed Impacts

Southeastern South America (parts of Argentina, Southern Brazil and Uruguay) underwent some of the most consistently increasing trends in precipitation during the 20th century. The rainfall increase has beneficed crops and pastures productivity, mainly for summer crops, and has partly contributed to a significant expansion of agricultural area, particularly in climatically marginal regions of the Argentinean's Pampas (Barros, 2008). Comparing the period 1930-60 and 1970-2000, maize and soybean yields increased by 34% and 58 % in Argentina, 49% and 57% in Uruguay and 12% and 9% in South Brazil (Magrin et al, 2007a, b). It is unclear if current agricultural production systems, which evolved partly in response to enhanced climate conditions, may remain viable if climate reverts to a drier epoch (Podestá et al., 2009).

According to Lobell and Field (2007) the temperature increase that occurred since 1981 resulted in annual combined losses for wheat, maize and barley crops representing roughly 40 Mt or $5 billion per year, as of 2002. While these impacts are small relative to the technological yield gains over the same period, the results demonstrate already occurring impacts of climate trends on crop yields at the global scale. In central Argentina simulated potential wheat yield has been decreasing at increasing rates since 1930 (-28.3 kg/ha/year between 1930 and 2000, and -52.7 kg/ha/year between 1970 and 2000) in response to increases in minimum temperature during October-November (+0.37°C/decade during 1930-2000, and 0.6°C/decade between 1970 and 2000) although this effect was partially reverted for increases in precipitation in the less humid zone (Magrin et al., 2009).

Damatta et al (2009) reviewed the effects of the climate changes on crop physiology. Many crops, such as soybean, common bean, maize and sugarcane will probably respond to the elevation of CO2, combined with elevation of temperature and lack or excess of water, by increasing productivity due to higher growth rates related to a fertilization effect and better water use efficiency. However, these authors also highlight the fact that food quality is likely to change in many cases. As crops respond to elevation of CO2 by increasing photosynthesis, they in general will take more carbon in relation to nitrogen. As a consequence, fruits will be expected to have higher sugar contents. On the other hand, as less nitrogen is taken up in relation to carbon, the protein content of cereals and legumes might decrease, therefore decreasing food quality in general.

27.3.4.2. Future Impacts

Numerical modeling experiments suggest that, in mid- to high-latitude regions, moderate to medium local increases in temperature (1– 3 °C) associated CO2 increase can have beneficial impacts on crop yields, but in low-latitude regions even moderate temperature increases (1–2 °C) are likely to have negative impacts on yield of major cereals (Easterling et al., 2007, Marin et al. 2011). Although work performed on the basis of observations of past and present behavior of crops have been suggesting that developing countries located in tropical regions (as happens in parts of South America) will have their agriculture impaired by the climatic changes (Tubiello and Fisher, 2007).

In Southeastern region of South America, climate change could benefit some crops until the middle of the century, although great uncertainty surrounds the damage that could be caused by greater year-on-year climate variations and interdecadal climatic variability. In Uruguay agricultural and forestry output is expected to climb steadily until the 2030s or the 2050s depending on emission scenario (A2, B2) (ECLAC, 2010a). In the Argentinean Pampas average yields of soybean, maize and wheat could remain almost stable or increase slightly if CO2 effects really occur. Increases in temperature and precipitation will benefit crops toward the Southern and Western zone of the Pampas, conversely in parts of the north and central Pampas's some yields could fall. The higher yields driven by climate change are likely to occur in areas which are considered peripheral mainly because of their fragile soils, which make the expansion of agriculture in those areas a fairly difficult prospect (Magrin et al., 2007; Magrin et al, 2009; Travasso et al., 2009; ECLAC, 2010b). In South of Brazil the CO2 fertilization effects could increase irrigated rice grain yield, in particular the very early cultivars (Walter et al., 2010). Also bean productivity is expected to increase under ongoing technological advancements and considering CO2 effects. If technological improvement is considered, the productivity of common bean and maize is expected to increase between 40% and 90% (Costa et al., 2009). Sugarcane production will be benefited as warming could afford its expansion of planted areas towards the south, where currently low temperatures are a limiting factor (Pinto et al, 2008). Increases in crop productivity could reach 6% in Sao Paulo state towards 2040 (Marin et al., 2009). In Paraguay the yields of soybean and wheat and the productivity of beef-raising could remain almost stable or increase slightly until 2030 (ECLAC, 2010b).

In Chile and Western Argentina, yields could be affected by water limitation. In the Chilean's basins situated between 30ºS and 42ºS the availability of irrigation water will decrease during critical periods, as water flows decline and glaciers gradually disappear. Atmospheric warming, water shortages and increased evapotranspiration will reduce productivity of winter crops (wheat, oats and barley), fruit, vines and radiata pine. Deciduous fruit trees (pomes, raspberries, blueberries and cherries) will fare worst because of the reduction in hours of cool and increases in high temperatures. Conversely, rising temperatures, more moderate frosts and more abundant water will benefit all species toward the south (Meza y Silva, 2009; ECLAC, 2009). In the northern Patagonia (Argentina) fruit- and vegetable-growing will suffer. The projected drop in rainfall will reduce average flows in the River Neuquén which will affect horticultural activity, including the growing of pip fruits (apples and pears), vines and, to a lesser extent, stone fruits. In the northern part of the Mendoza basin the projected rise in water demand, merely from the population growth estimated for 2030, may compromise the availability of subterranean water for irrigation, pushing up irrigation costs to levels that will force many producers out of farming. In addition, water quality will be reduced by the worsening of existing salinization processes (ECLAC, 2010b).

In Central America, Northeastern Brazil and parts of the Andean region, climate change could seriously affect not only the local economies but also the food security. According to Lobell el atl (2011), Battisti and Naylor (2009) and Brown and Funk (2008) is very likely (>90%) that growing season temperatures in the tropics and subtropics by the end of the 21st century exceed the most extreme seasonal temperatures recorded from 1900 to 2006. Their results suggest that unprecedented seasonal average temperature will affect parts of tropical South America, east of the Andes and Central America by 2080-2100 and this can be detrimental to regional agricultural productivity and human welfare and to international agricultural markets. In Northeast Brazil, several authors report declining of crop yields for subsistence crops such as beans, corn and cassava (Lobell et al., 2008; Margulis et al., 2010). Increase in air temperature will cause a significant reduction in the areas currently favorable to cowpea bean crop (Silva et al., 2010). In addition, lands ability to support crops could change. If no adaptation action will be accomplished, the warming up to 5.8 °C foreseen for 2070, could make unfeasible the coffee crop in the Southeast region of Brazil (Minas Gerais and Sao Paulo States). It has been mentioned that by 2070 the coffee crop may have to be transferred for southern regions, where frost risk will be much lower (Camargo, 2010). A substantial increase in the size of low climatic risks areas for the production of Arabica coffee are expected in the extreme South of Brazil, mainly for mean temperature increases of 3◦C (Zullo et al., 2011). Areas with low climatic risks will become available mainly in the border with Uruguay and North of Argentina. Also, the impact of future climate on Brazilian potato production will be more important in currently warm areas, which today allow potato production all year round. In such zones, plantings will be restricted to a few months. For cooler areas, major drawbacks on potato production are not expected (Lopes et al., 2011). In Central America current temperatures are close to or slightly higher than optimum for agriculture. Warming conditions combined with more variable rainfall is expected to reduce the productivity of the agricultural sector (including bean, rice and maize) endangering the food security of large segments of the population and increasing poverty (ECLAC, 2010c). However, these modeling data have to be considered with caution, as very few or no experiments have been performed with crop plants to check how they will physiologically respond to climate change factors. It will be crucial that such experiments will be performed and the results incorporated in the models so that they become more realistic in the future, especially considering that the extrapolation from experiments reported for different varieties of the same species (soybean, maize, common bean for example) may be limited due to the fact that the varieties used as crops in Central and South America have been modified by classical genetics to adapt to the prevalent conditions found in these regions.

[A table will be added with main impacts]

Vignola et al (2002) investigated if the impact of climate change on farm soils in the tropics is the combined result of short-term soil management decisions and expanding precipitation extremes. They found that his is particularly true for cultivated lands located in steeply sloping areas where bare soil is exposed to extreme rainfall such as the Birris watershed in Costa Rica.

Climate change may alter the current scenario of plant diseases and their management, and these changes will certainly have effects on productivity (Ghini et al 2011). In Argentina, years with severe infection of late cycle diseases in soybean could increase up to 60% by the end of the century. In the maize-growing segment, severe outbreaks of the Mal de Rio Cuarto virus (MRCV) are expected to become more frequent throughout the endemic area, especially in the northern part (by over 30%). Wheat head fusariosis will increase slightly in the south of the Pampas region (10%) and decrease in the northern part (by up to 20%), (Martinez et al., 2011, ECLAC, 2010b). Potato late blight (*Phytophtora infestans*) severity is expected to increase under future conditions in Perú (Giraldo et al., 2010). On the other hand, there is uncertainty related to the how plants will respond to diseases in a world affected by climate change. As plants are expected to increase photosynthesis and accelerate their metabolism under the effect of elevated CO2 and higher temperature (Buckeridge et al. 2008), it is possible that such effects will offset many of the disease effects in the future.

The impact of climate change on regional welfare will depend not only on changes in yield, but also in international trade. In the near term (by 2030) global cereal price could change between increases of 32% for a low-productivity scenario and reductions of 16% under an optimistic yield scenario. Rise in prices could benefit to net exporting countries. In Brazil, for instance, aggregate gains from terms of trade shifts outweigh the losses due to the direct effect of climate change. Despite experiencing significant negative yield shocks some countries stand to gain from higher commodity prices (Hertel et al., 2010).

Related to livestock production Seo et al., (2010) reported that the impacts of climate change would vary by species and climate scenarios. For example, under a hot and dry scenario by 2060, beef cattle decrease by 3.2%, dairy cattle by 2.3%, pigs by 0.5%, and chickens by 0.9%, which is offset by a large increase in sheep by 7%. Large changes are observed in the Andean countries. Under this scenario, dairy cattle increase in Uruguay and Argentina, but decrease elsewhere. The increase in sheep occurs mostly in the Andes mountain countries such as Chile, Colombia, Ecuador, and Venezuela. Under a milder and wetter scenario, beef cattle choice declines in Colombia, Ecuador, and Venezuela, but increases in Argentina and Chile. Sheep increase in Colombia and Venezuela, but decrease in the high mountains of Chile where chickens are chosen more frequently. Future climate could strongly affect milk production and feed intake in dairy cattle in Brazil. Furthermore, it has been demonstrated that climate change as projected by the A2 and B2 scenarios leads to substantial modifications in the present day areas suitable for livestock, particularly at the main Pernambuco production regions (Silva et al, 2009).

27.3.4.3. Adaptation Practices

Appropriate soil and technological management as well as genetic improvements may very likely induce an increase in some crops yield despite the unfavorable future climate conditions. In Argentina, genetic techniques, specific scientific knowledge and land-use planning are viewed as promising sources of adaptation (Urcola et al., 2010). Anticipating planting dates by 15-30 days could reduce negative impacts in maize and wheat crops in Argentina (Travasso et al, 2009; Magrin et al, 2009). In Chile the best alternative for adaptation in maize and wheat correspond to adjustments in sowing dates and fertilization rates (Meza & Silva, 2009). Furthermore, in central Chile and southern Pampas in Argentina warmer climates lead to extended growing seasons and shortens crop cycles, so it would be possible to perform two crops in the season increasing productivity per unit land (Meza et al., 2008; Monzon et al, 2007). In South Brazil, a good option for irrigated rice could be to plant early cultivars (Walter et al., 2010). Deficit irrigation could be an effective measure for water savings in dry areas such as the Bolivian "Altiplano" (quinoa), central Brazil (tomatoes) and northern Argentina (cotton) (Geerts and Raes, 2009). Adaptation strategies for coffee crops in Brazil include: shading management system (arborization), planting at high densities, vegetated soil, correct irrigation and breeding programs (Camargo, 2010). Shading is also used in Costa Rica and Colombia.

An effective manner for assisting societies to be better prepared and adapt to possible climate change scenarios is by assisting them to cope better with current climate variability. The Climate Risk Management approach as understood in the IRI seeks managing the entire range of climate-related risks: from the very unfavorable conditions up to the risk of missing opportunities. This approach is based on four main pillars: 1) Identify vulnerabilities and potential opportunities due to climate variability and/or change for a given system; 2) Quantify uncertainties in "climate information"; 3) Identify technologies and practices that optimize results in normal or favorable years and reduce vulnerabilities to climate variability and change (crop diversification, crop rotations, improved tillage systems, increased water soil storage, improved crop water use efficiency, drought resistant cultivars); 4) Identify interventions, institutional arrangements and best practices that reduce exposure to climate vulnerabilities and enable the opportunistic exploitation of favorable climate conditions (Baethgen, 2010). The use of climatic forecasts in agricultural planning is an adaptation measure to cope with current climatic variability. There is a number of climatic indices related to climate and crops production variability. In Argentina, SOI for maize and SSTSA for soybean and sunflower were the best indicators of annual crop yield variability. SOI corresponding to September and May were useful in counties contributing to 71% of maize production; SSTa SA (June) was the best for soybean in the main producing region; and SSTa SA (March) could be useful for sunflower in the northern part of the region (Travasso et al., 2009). For these forecasting tools to be adequately used, biological information derived from experiments will have to be combined so that the lowest uncertainty possible will be reached in forecasting systems. In order to achieve a reasonable level uncertainty, the Central and South Americas region lacks integrated research programs that could be established both through extant Institutions integration as well as the foundation of an international institution that centralizes and organizes the data for the region, therefore providing means for reliable forecasting about the impacts of the climate changes so that solutions are more quickly reached in the future.

27.3.5. Human Settlements, Industry, and Infrastructure

Urban areas in Latin America and the Caribbean (LAC) are hotspots of vulnerability to floods, heat waves, and other hazards that climate change is expected to aggravate (Vergara, 2008; Satterthwaite et al 2007. These roles create unique challenges and opportunities for urban mitigation and adaptation responses, and for mainstreaming them with development goals (Hardoy & Pandiella 2008; Romero Lankao 2008). Some aspects of urban development in LAC shape sources and trajectories of adaptive capacity and responses. These are: high levels of urbanization (79.4%); localization patterns of economic activities and population in risk prone areas (Nichols et al 2008; Barros et al 2008); the new growth trend taking place in smaller, less capable, urban areas (Ferreira et al., 2011; Hardoy & Romero Lankao 2011) and ongoing development issues that maintain a large urban poor population (34.1% of urban dwellers in average but with higher in Bolivia, Nicaragua and Haiti, Winchester 2008). Within most cities in LAC, climate risks fall disproportionately on low-income groups who occupy high-risk sites, have the least adequate provision of protective infrastructure and services and no formal tenure over the land they occupy (Smolka 2008. Climate change brings another level of stress to these already vulnerable populations (Roberts, 2009; Pielke et al 2003; Romero Lankao 2011).

Climate variability and change already have a variety of implications for urban dwellers, buildings, and economic sectors (e.g., industry, retail and commercial services) and on the network-infrastructures, such as energy, waste water and transport systems (Gasper et al., 2011). Hydroelectricity in Brazil is vulnerable to changes in precipitation. Tourism operators might be sensitive to changes in beach property along the coast of Rio de Janeiro, and anything that influences the perceptions of tourists (real or imagined, Gasper et al., 2011). Floods will likely impact retail and commercial business located in newly formed floodplains (Gasper et al., 2011). Hurricanes, whose intensity has increased in recent years, bring rains that besides their possible water benefits become ideal conditions for cholera, malaria and dengue (Moreno 2006). Slums are particularly vulnerable because sanitation infrastructure and trash pickup are not available, and the resulting pools are breeding grounds for mosquitos (ECLAC 2008).

The population has continued to migrate from the countryside to the cities. The rate of poverty is generally higher in rural than urban areas. Soil degradation and natural disasters are factors that contribute to this migration. Thus, Latin America is a highly urban region. Seventy-seven per cent of the population lives in cities, which increases to almost 90%in the Southern Cone. Mega cities are commonplace. Irrational growth of cities in combination to the lack of urban planning presents multiple environmental consequences: increases in solid waste as well as liquid residues, atmospheric contamination, pressure on surrounding ecosystems, settlements in vulnerable areas, among others; but in turn, the loss of urban environmental quality directly affects the health and welfare of citizens. In addition, urban sprawl and the preference for automobiles over public transport has created congestion, more and longer journeys, and greater energy consumption that increases air contamination, so making urban transport another regional challenge. (*Ocampo and Ros, eds. 2011)*. The automobile fleet continues to grow; although the ratio per 100 inhabitants remains low at fewer than 20. The number of light vehicles is expected to double between 2000 and 2030, and by 2050 to be triple the 2000 number (*Samaniego 2009)*

Hsiang (2010) discusses the economic impact of surface temperatures for both economic development and climate change policy. This study shows that in 28 Caribbean-basin countries, the response of economic output to increased temperatures is structurally similar to the response of labor productivity to high temperatures, a mechanism omitted from economic models of future climate change. They suggest that current models of future climate change that focus on agricultural impacts but omit the response of workers to thermal stress may underestimate the global economic costs of climate change.

Current findings point that urban areas are already faced with an array of changes in climate parameters: glacier shrinkage in the Andes; decreases in precipitation in Chile; increases in flood events; and more intense El Niño/La Niña events since the 1980s (Hegglin and Huggel 2008; Barros et al., 2008; Andrade and Scarpati 2007; MSDP 2002; Moreno 2006). Some of these are related to climate change and others that are not (e.g., industrial, technological, de Sherbinin et al., 2007, Satterthwaite et al., 2007), but together these hazards may present a complexity that will increase societal impacts. E.g., most coastal Brazilian cities are exposed to threats such as sea level rise, storm surges, floods, and landslides, some of which (e.g., landslides) are related to land use practices and ineffective urban planning (Ferreira et al., 2011).

Projected changes due to multiple stressors, including urbanization and megacities are issues of growing importance in South America and climate change brings the perspective of widespread impact. Urbanization has brought significant local climate change for megacities (heat waves, acute pollution episodes, intense rainfall events, urban flash floods and landslides, etc.). In the metropolitan region of the city of São Paulo, various studies (Nobre et al 2010) have suggested that the urbanization has brought significant local climate change for megacities, and observed changes in extremes of rainfall detected in previous studies for Southeastern South America (Marengo et al 2009a, c) have been amplified by the urbanization effect. In fact if the number of days with rainfall above 50 mm in the city of São Paulo were almost absent during the 1950´s and now they occur between 2 to 5 times per year by 2000-2010.

27.3.6. Renewable Energy

Renewable energy (RE) is any source of energy that can be renewed within a reasonable length of time so that, differently from fossil fuels, accumulation of green house gases in the atmosphere will be avoided. In Brazil, 47% of the energy in 2007 came from renewable sources. Hydroelectric power plants alone responded for 83% of Brazil's power generation in 2006 (Lucena et al. 2009).These authors demonstrated that hydro and wind energy and biodiesel production shall be particularly sensitive to climate change in Brazil. Therefore, renewable energy is one of the ways to mitigate the effects of the global climate changes (GCC) by offsetting the effects of the green house gases that tend to elevate the temperature of the atmosphere and induce changes in the climate. Due to the importance that renewable energy has in mitigation of GCC, it is of great importance to know what is going to happen with the implementation of projects of RE as well as with crops that provide bioenergy, which are by far the most important sources of RE in South and Central Americas.

For historical reasons, Central and South Americas developed sugarcane as a bioenergy feedstock. This is due to the fact that sugarcane produces large amounts of sugar in its stem and also because sugar mills were installed in many countries, especially Brazil and Cuba. Brazil has, by far, the most intensive production of RE in the form of bioethanol, which is used by 90% of the cars in the country (Goldenberg, 2008). Furthermore, biodiesel is 5% of all diesel in the country. In 2011, countries like Colombia and Chile are starting efforts to increase their bioenergy production from sugarcane and eucalyptus respectively. As the continent has a long latitudinal length, the expected climate changes are very complex due to a wide variety of climate conditions. This imposes the problem of using different crops in different regions. Whereas in Mexico, Central America and the Northeast region of Brazil crops like Agave could be used as a bioenergy feedstock, in the tropical regions of Cuba, Venezuela, Colombia and Brazil, the grasses (mainly sugarcane) tend to be used. Other grasses like sweet sorghum and miscanthus are already in use or likely to be used in the near future for bioethanol production. For biodiesel, in Brazil 80% is produced from soybeans, but there are promising new sources such as the African palm dendê.

Biofuels are promising sources of renewable energy, but might imply potential problems such as those related to a positive net emission of greenhouse gases, threats to biodiversity, increase in food prices and competition for water resources, all of which can be reverted or attenuated (Koh & Ghazoul 2008). Besides bioethanol, the sugarcane agro industry in Brazil combusts the bagasse, in a process called cogeneration, providing power for the bioethanol industry and increasing sustainability. The excess heat energy is used to generate bioelectricity, thus allowing the biorefinery to be self-sufficient in energy utilization (BNDES & CGEE, 2008). In 2005/2006 the production of bioelectricity was estimated to be 9.2 kWh per ton of sugarcane (Macedo *et al.*, 2008), approximately 2% of Brazil's total energy generation production (MME, 2008).

Most feedstocks now on the scope of bioenergy production in Central and South America are grasses and display C4 photosynthesis. In the case of sugarcane, by far the most important one, the responses of the plant to elevation of CO2 concentration by up to 720ppmv have been shown to be positive in terms of biomass production and principally regarding water use efficiency (De Souza et al., 2008). Modeling of the sugarcane crop behavior under elevation of CO2 concentration considering also the best practices for sugarcane cropping, revealed that bioethanol production might be mildly affected by GCC.

The production of energy from renewable sources such as bioenergy, hydropower, wind power and others are greatly dependant on climatic conditions and therefore may be impacted in the future by the GCC. Lucena et al (2010a) analyzed the vulnerabilities of renewable energy production in Brazil for the cases of hydropower generation and liquid biofuels production, given a set of long-term climate projections for the A2 and B2 IPCC emission scenarios. The most important result found in this study is the increasing energy vulnerability of the poorest regions of Brazil to GCC. Both biofuels production (particularly biodiesel) and electricity generation (particularly hydropower) may negatively suffer from changes in the climate of those regions.

Lapola et al (2010) indicated that the planned expansion of biofuel plantations in Brazil could potentially cause both direct and indirect land-use changes (e.g., biofuel plantations replace rangelands, which replace forests). Their simulation for 2020 shows that direct land-use changes will have a small impact on carbon emissions because most biofuel plantations would replace rangeland areas. This study also shows that sugarcane ethanol and biodiesel derived from soybean contribute each with about half the indirect deforestation projected for 2020 (121.970 km^2), which would create a carbon debt that c. 250 years to be payed back by biofuels replacing fossil fuels.However, indirect land-use changes, especially those pushing the rangeland frontier into the Amazonian forests, could offset the carbon savings from biofuels.

Although the prospects of energy production by sugarcane industry are very promising, the increase in global ethanol demand, driven by global concern for addressing climate change, is leading to the development of new hydrolytic processes which aim at converting cellulose and hemicelluloses into ethanol (Buckeridge *et al.*, 2010; Dos Santos *et al.*, 2011). The expected increase in convertible biomass has the potential to decrease the requirement of land for biomass crops. If such technologies are developed, there is high probability of diminishing social (e.g. negative health effects due the burning process, poor labor conditions) and environmental impacts (e.g. loss of biodiversity, water and land uses) and at the same time improving the economic potential of sugarcane. A similar situation is expected if an increase in productivity of sugarcane and other bioenergy feedstocks are planted in a high productivity environment.

Other renewable energy sources—such as wind power generation—may also be vulnerable, raising the need for further research. In particular, Lucena et al (2010b) assess the availability and reliability of wind power on future climates since the untapped wind power potential is known to be impressive. For the extreme A2 and B2 emission scenarios results based on the HadCM3 general circulation model and the analysis of the country's wind database indicate that the wind power potential in Brazil would not be jeopardized in the future due to possible new climate conditions. On the contrary, improved wind conditions are expected, particularly in the Northeast coast of the country.

Minimization of the impact of sugarcane on biodiversity and the environment is expected to improve its sustainability. As the demand for bioethanol increases, improvement of productivity will result in a greater demand for land for sugarcane production. In this context, an expansion of land under sugarcane production is likely, especially in Brazil's Central-South region (Lapola *et al.,* 2010). Part of the Central-South region of Brazil is occupied with sugarcane and soybean crops. However, this region also includes the cerrado biome, which requires protection from expanding agriculture (Sawyer 2008). Although there are no current plans for expansion of sugarcane production in the Amazon (BNDES & CGEE, 2008), it is important to ensure the protection of this unique region of Northern Brazil and Colombia as sugarcane grows into a commodity and policy is formed (Sawyer 2008).

Initiatives such as the soy moratorium in the Amazon have an inhibitory effect over deforestation rates. Rudorff et al. (2011) showed that from 2008 to 2010 soybean was planted only on 0.25% of deforested land, which represents 0.027% of the total soybean cover in Brazil. However, in total, increased demand for agricultural commodities will continue to be a driver behind the conversion of primary and secondary forests in Brazilian tropical forests and savannas (Sawyer 2008, Fargione et al. 2011). Increased protection of natural areas in these species-rich areas is necessary to preserve biodiversity in theface of these pressures (Brooks et al. 2009). If carefully managed, biofuel crops can be even used as a means to regenerate biodiversity as proposed by Buckeridge et al. (2011). These authors highlight the fact that the technology for tropical forest regeneration is now available and that forests could share land with biofuel crops (such as sugarcane) with the advantages that forests have for mitigating fossil fuel carbon emissions.

27.3.7. Human Health, Well-Being, and Security

An ever-increasing body of scientific literature warns that climate change is to impose a profound and costly socio-economical burden on human health (McMichael et al., 2006; Confalonieri et al. 2007; Frumkin 2008; Jones et al. 2008; Laferty 2009; Tonnang et al. 2010; Parham & Michael 2010; Rohr et al. 2011). Climate factors were reported to affect human health outcomes in different countries of Latin America where there are important endemic infectious diseases that are sensitive to climate variability, such as malaria and dengue fever. Weather and climatic extremes were also observed as causing social impacts in this region. In 2008, a general review of aspects related to climate and health in Latin America was published (Rodriguez-Morales et al., 2008).

The vulnerability of the human population in Latin American and the Caribbean Region to the impacts of climatic factors and events is well recognized (Winchester & Szalachman, 2009). Many factors contribute to this including urbanization patterns; poverty; institutional and cultural aspects; poor sanitation, among others. In Brazil, a national study on population vulnerability to the impacts of climate was based on aggregate indices containing, epidemiological, climatic and social-economic indicators (Confalonieri et al 2009). This has been followed by a regional comprehensive study on the possible economic and demographic impacts of climate scenarios and the consequences for health and health care costs (Barbieri and Confalonieri, 2011; Confalonieri et al, 2011). A more recent study assessed the multi-sectoral vulnerability of municipalities in southeastern Brazil as reacted to different climatic scenarios, also using aggregated social-environmental and health indicators (FIOCRUZ, 2011).

Olivero-Verbal (2011) concludes that Colombia's populations rely on the Magdalena River basin as a source of water, but the river is polluted with domestic sewage, industrial discharges, and sediments from deforestation, impacting health quality. Illicit drug crops and colonization are deteriorating the forest and threatening biodiversity. Pesticides, some banned, are misused in agriculture, leading to human exposure. Gold mining areas are sources of mercury, and children living in cities such as Cartagena are exposed to lead. Polycyclic aromatic hydrocarbons and emerging pollutants such as perfluorinated compounds have been found in samples from industrialized areas.

27.3.7.1. Infectious Diseases

Mendonça (2009) has observed, for the period 1997-2007, an expansion of the area of distribution of dengue fever in the southern region of Brazil. During this same period an increasing regional trend on average surface temperature was detected, as well as a concentration of more intense rainfall episodes. Jury (2008) studied the dengue incidence in Puerto Rico, as related to temperature and precipitation variability. It was found that seasonal fluctuations of dengue in the period 1979-2005 were driven by rainfall increases from May to November. Year–to-year variability in dengue cases was positively related to temperature but only weakly associated with local rainfall and an Index of El Nino – Southern oscillation (ENSO). Dengue was projected to increase in the future due to the fact that temperatures in the Caribbean are rising with the influence of global warming. The patterns of dengue incidence were studied in three Caribbean countries (Trinidad y Tobago, Barbados and Jamaica) in relation to climate variability, for the period 1980-2003. The disease has had a marked seasonality and epidemics were associated to the onset of rainfall and increasing temperatures; the probability of epidemics was also higher during El Niño periods. An index based on moving average temperature seemed to be effective for gauging the potential for onset of dengue (Amarakoon et al, 2008).

The impact of climate variability on the incidence of dengue in the State of Veracruz, Mexico, was examined for the period 1995-2003. Each degree centigrade increase in Sea Surface Temperature (an indicator of ENSO) was followed by significant increases (up to 46%) in the number of dengue cases, with lag times from 16 to 20 weeks. (Hurtado-Diaz, et al, 2007). Brunkand et al (2008) found similar results in a study in northern Mexico: Every increase in 1ºC in sea surface temperatures (El Nino region 3.4) was followed by a 19.4% increase in dengue incidence, 18 weeks later. Another dengue risk study, developed in South eastern Brazil (Dibo et al, 2008) focused on weekly variations of dengue vector densities. Four entomological indices were associated to higher temperatures measured locally as well as with rainfall intensity.

Lowe et al. (2011) developed spatio-temporal modelling of climate-sensitive dengue in Brazil, concluding that seasonal climate forecasts could have potential value in helping to predict dengue incidence months in advance of an epidemic in South-Eastern Brazil. These studies are useful for providing baseline information for identifying potential long-term effects of global climate change on dengue expected in the coming decades.

Another endemic infectious disease of Latin America which was investigated in relation to climate factors was the leishmaniases. Cardenas et al. (2006) analyzed the impact of climate variability associated with ENSO during 1985-2002 on the incidence of leishmaniasis (cutaneous and visceral forms) in Colombia. The authors found that during El Nino episodes, cases of leishmaniasis increased whereas the disease has decreased during La Nina phases. Further analysis, in a broader area of Colombia, has shown mixed results, with some areas having increases in incidence during La Nina (Cardenas et al, 2008). Also, Valderrama-Ardila et al. (2010) studied the largest outbreak of American cutaneous leishmaniasis in Colombia, which occurred in 2003, and concluded that predictor variables were land use, elevation, and climatic variables such as mean temperature and precipitation. Gomez et al (2006) studied the incidence of leishmaniasis as related to El Niño and La Niña indicators in Bolivia. They found that during 1991-2000 the disease incidence increased 67% during La Niña and that decreased by 40% during El Niño years. Chaves & Pascual (2006) studied monthly data, from 1991 to 2001, of cutaneous leishmaniasis incidence in Costa Rica, in relation to climate variables. They have concluded that Linear Models using temperature and Multivariate ENSO Index can predict satisfactorily the incidence of the disease up to 12 months ahead. In a second study (Chaves et al, 2008) the authors have found that forest cover was associated with the modulation of temporal effects of ENSO at small spatial scales, revealing a complex interplay between environmental factors and the pattern of leishmaniasis..

Feliciangeli et al (2006) studied the transmission dynamics of visceral leishmaniasis (VL) in a closed focus in western Venezuela. They found that its vector density exhibit a temporal variation driven by the bimodal annual pattern of precipitation with the highest population densities in April and December. Also they found that prevalence of Leishmania in humans was correlated with distance of the houses from the woodland and with sand fly abundance.

Herrero–Martinez & Rodriguez–Morales (2010) have analyzed a time series of dengue cases in western Venezuela for the period 2001-2008. They have concluded that there has been a significantly higher incidence of dengue during El Niño periods, as indicated by the Oceanic Niño Index (ONI). In Guadeloupe (French West Indies), in the Caribbean, Gharbi et al (2011) have developed a dengue incidence model (2001-2006) for the assessment of the impact of meteorological variables on the prediction of incidence and outbreaks of the infection. They found that temperature was a better predictor than rainfall or humidity, with a three-month advance time.

A field study on the role of climate factors on population dynamics of the main mosquito species vector of yellow fever in the tropical Americas (*Haemagogus janthinomys*) has shown a positive correlation between mosquito densities and temperature and relative humidity (Pinto et al,2009).

Malaria, an important endemic infection in Latin America, was also investigated in relation to climate variables. Ruiz et al (2006) developed a model to represent the transmission of "falciparum" malaria in Colombia. They have found that temperature was the most relevant climatic parameter driving disease incidence, and outbreaks were likely to occur during the favorable epochs following the onset of El Niño warm events.

Other studies identified strong linkages between ENSO with malaria in Colombia (Rúa et al. 2005; Mantilla et al. 2009; Poveda et al. 2011), in Ecuador and Peru (Anyamba et al, 2006), in Venezuela (REF), French Guiana (Hanf et al. 2011), as well as in Amazonia (Olson et al. 2009).

On the other hand, Dantur Juri et al. (2009) studied malaria transmission in two localities in north-western Argentina, and found that the temporal distribution malaria vectors (An. Pseudopunctipennis) exhibit a seasonality, and that malaria cases are influenced by maximum mean temperature, mean temperature and humidity. Also, Dantur Jury et al. (2010) found that tha abundance patterns of *Anopheles pseudopunctipennis* and *Anopheles argyritarsis* in northwestern Argentina are related to temperature, rainfall and relative humidity.

As for the relations between non-infections diseases and variables a study development in Barbados (Depradine & Lovell, 2007) observed that there was a high correlation between vapor pressure and asthmatic attacks, with a three-week lag time.

27.3.7.2. Respiratory Diseases

Martins et al. (2006) reviewed the vehicular emissions inventory for the light- and heavy-duty fleet in the metropolitan area of São Paulo (MASP), Brazil. The mean CO and NOx emission factors (in g km-1) were, respectively, 14.6 ± 2.3 and 1.6 ± 0.3 for light-duty vehicles, compared with 20.6 ± 4.7 and 22.3 ± 9.8 for heavy-duty vehicles. The main VOCs classes identified were aromatic, alkane, and aldehyde compounds. For the heavy-duty fleet, NOx emission factors were approximately 14 times higher than those found for the light-duty fleet.

Martins & Andrade (2008) employed a three-dimensional Eulerian photochemical model o estimate the impact that organic compounds have on tropospheric ozone formation in the Metropolitan Area of São Paulo (MASP). They found correlation coefficient relative to observations for ozone ranged from 0.91 to 0.93. In the simulations employed to evaluate the ozone potential of individual VOCs, as well as the sensitivity of ozone to the VOC/NO x emission ratio, the variation in anthropogenic emissions was estimated at 15% (according to tests performed previously variations of 15% were stable).

Gurjar et al. (2010) evaluated human health risks in megacities due to air pollution, and identified Sao Paulo as one of megacities at the low end of excess cases in total mortality from pollutants.

The effects of fires associated with sugarcane cultivation on respiratory health of elderly and children in the State of Sao Paulo, Brazil, are examined by Uriarte et al (2009). Respiratory morbidity attributable to fires accounted for 113 elderly and 317 child cases, approximately 1.8% of total cases in each group. Although no chronic effects of fire were detected for the elderly group, an additional 650 child cases can be ascribed to the long-term cultivation of sugar cane increasing to 5.4% the percent of children cases that can be attributed to fire.

27.3.7.3. Cutaneous Diseases

Llamas-Velasco & García-Díez (2010) discuss the possible increase in cuteneous pathologies due to increasing temperatures including cutaneous xerosis,but also skin cancer by increasing exposure to solar radiation and photo-aging. Salinas et al. (2006) found that cancer skin cancer in Chile is mostly associated with climatic and geographic variables.

27.3.7.4. Other Diseases

Ciguatera fish poisoning (CFP) is a circumtropical disease caused by ingestion of a variety of reef fish that bioaccumulate algal toxin. Distribution and abundance of the organisms that produce these toxins, chiefly dinoflagellates of the genus Gambierdiscus, are reported to correlate positively with water temperature. Consequently, there is growing concern that increasing temperatures associated with climate change could increase the incidence of CFP along the Caribbean Sea (Tester et al. 2010).

27.4. Adaptation Opportunities, Constraints, and Limits

27.4.1. Adaptation Needs and Gaps

In Central and South America, adaptation efforts are heavily constrained by limited funding available from central governments for this purpose. Most government responses to disasters are mainly reactive rather than preventive. Some early warning systems are being implemented, but the capacity of responding to a warning is often very limited, particularly among poor populations. Indigenous knowledge, if properly combined with state-of-the- art technologies, present a valuable resource for helping with adaptation of rural communities.

27.4.2. Practical Experiences of Adaptation, including Lessons Learned

In the Meso American Pacific rim, Eakin et al (2011) identified both gradual systemic processes as well as specific environmental and market shocks as significant drivers of livelihood change across the region. Agronomic adjustments and new forms of social organization were among the more significant responses of farmers to these changes. The assessment indicates that public interventions in support of adaptation should focus on enhancing farmers' access to market and technical information and finance, as well as on increasing the viability of farmers' organizations and cooperatives.

In Honduras, Winograd (2007) investigate how to define and use indicators to provide and communicate information for policy-making and decision-making to reduce environmental, social, and economic vulnerability and increase sustainability. Analysis from Honduras on pre- and post- Hurricane Mitch (October 1998) environmental, social and economic conditions and vulnerability, and evaluations of optional response strategies, are presented as examples of how to produce meaningful information to close the gap between research and action. In all circumstances, it is important to link spatial entities (villages, landscapes, watersheds, ecosystems) to social entities (individuals, families, communities, towns) in such a way as to acknowledge a reality that implies both spatial and temporal dimensions.

Tucker et al (2010) explore the role of risk perception in adaptation to stress through comparative case studies of coffee farmers' responses to climatic and non-climatic stressors in Central America and Mexico, and found that farmers who associated events with high risk were not more likely to engage in specific adaptations. Adaptive responses were more clearly associated with access to land than perception of risk, suggesting that adaptation is more a function of exogenous constraints on decision making than perception.

Leibing et al (2009) investigate the potential of two pine varieties in central America under future climate change scenarios, and they conclude that by 2020 the lowland areas in Central America are expected to be most productive because of their promising performance under rather hot and wet climates of these two varieties.

In Chile, Young et al (2010) document the exposures and sensitivities faced by the community in the Elqui River Basin of Northern Chile to water and climate-related conditions in light of climate change. Community vulnerability occurs within a broader physical, economic, political and social context, and vulnerability in the community varies amongst occupations, resource uses and accessibility to water resources, making some more susceptible to changing conditions in the future. This case study highlights the need for adaptation to current land and water management practices to maintain livelihoods in the face of changes many people are not expecting.

In the Bolivian Altiplano, Validivia et al (2010) recognized that Andean rural communities are particularly vulnerable to changing social and environmental conditions, and discussed a process for developing new local knowledge that can be used to enhance adaptive processes, and outlined a strategy for linking science-based and indigenous methods to develop early warning systems that are an important part of coping strategies. This approach combines science and indigenous knowledge to enhance adaptive capacity.

Eakin and Wehbet (2009) focus on the specific mechanisms by which farm-level responses to globalization and environmental change feedback to affect the sustainability and resilience of the social– environment system, applied to two realities in Latin America, and they illustrate the collective and synergistic implications of farmers' livelihood and land use choices for the sensitivity of the region to future market and environmental shocks, as well as for the role of the landscapes in the global carbon cycle.

Adaptation strategies in the semi-arid northeast Brazil have been often implemented through local development initiatives without clear integration into development or even climate change policies. A recent project takes together climate and social vulnerabilities that adversely affect poor family farmers with low adaptive capacity. It is focused on implementing adequate technologies and building local capacity for introducing innovations and supplying technical assistance, as well as increasing the economic opportunities for participating farmers. Preliminary results show that participating family farmers managed to earn additional monthly income ranging from 32 to 106 US$/month. Such improvements may constitute an important improvement in rural livelihood if the positive changes of the project can be maintained or even expand in the future (Simões et al, 2010).

Ecosystem-based adaptation are the adaptation policies and measures that take into account the role of ecosystem services in reducing the vulnerability of society to climate change, in a multi-sectoral and multiscale approach (Vignola et al. 2009). However, cost–benefit analyses rarely emphasize biotic and abiotic entities that create ecosystem services, and markets commonly fail to protect ecosystem functions and related biodiversity adequately (Mooney 2010). Restoration actions focused on enhancing biodiversity should support increased provision of ecosystem services, particularly in tropical terrestrial biomes (Benayas et al. 2009).

27.4.3. Observed and Expected Barriers to Adaptation

Benegas et al (2009) study the adaptation of a river watershed in Nicaragua to drought and climate variability, and explains that one of the biggest challenges in the design of this methodology is the possibility to fix it in order to use it in other thematic fields (potable water, tourism, energy, among others); for that reason, it is advisable consider it as a reference for an adaptable methodology when designing strategies for adaptation to climate variability and climate change in these sectors.

27.4.4. Planned and Autonomous Adaptation

Autonomous adaptation proved to be fast in the agricultural sector of Argentina and rather effective in terms of immediate economic benefits. The expansion of the soybean was driven by international prices and new technological packages that included minimum or no-till practices. However, its geographical extension to former semiarid regions was possible because of the positive trend in precipitation that took place between the second half of the 1970s and the 1990s (Barros, 2008). The recovery of precolombine technologies to face water shortage and extended droughts is an autonomous adaptation that is being implemented in different indigenous communities in the Bolivian Altiplano, for example the water storage in Qhuthañas (Andersen & Mamani Paco, 2009). In Chile forestry and agricultural activities are expected to shift towards the south (Araucanía, Los Ríos and Los Lagos), where the climate will become more apt for them. An econometric model developed to estimate potential land use change in response to climate-driven shifts in land profitability found that the cultivated area would remain constant over time, but that the allocation of activities would change (ECLAC, 2009).

27.4.5. Interactions between Adaptation and Mitigation

La Rovere et al (2009) study the potential synergy between adaptation and mitigation strategies: production of vegetable oils and biodiesel in northeastern Brazil, where improvement of the social and economic conditions in these rural communities through the growth of vegetable oil crops is an important adaptation strategy vis-à-vis future climate change, constituting an income-generation activity in the biodiesel production chain. The use of vegetable soils as a feedstock for biodiesel production and fuel reduces CO2 emissions due to the displacement of diesel oil, thus it also contributes to a mitigation strategy. They identify potential barriers to an increase in vegetable oil production by small farmers in the region, and suggest the following: the use of selected seeds of several vegetable oil crops alongside subsistence crops, capacity building and technological and financial support to small farmers, and the building of logistics infrastructure and the appropriate institutional setting.

27.5. Case Studies

27.5.1. Hydropower

The linkages between climate change and hydropower are many and reflect quite interestingly the feedback mechanisms that affect this problem. On one hand, hydropower is seen a major contributor to mitigating GHG emissions worldwide but on the other it is a sector that relying on a resource so much related to climate as is water, suffers the potential impacts of climate change.

The Central and South America region set up a unique example to study these relations as described in this Box. According to the Special Report on Renewable Energy Sources and Climate Change Mitigation (Table 5.1 SRREN, IPCC, 2011) Central and South America are only second to Asia in terms of actual and potential generation in the world with 20% of total annual generation. The quality of water resources availability is the largest in the world with an average regional capacity factor of over 50%. Owing in part to the later, in relative terms compared to other sources of energy to generate electricity the region has by far the largest proportion of electricity being generated through hydropower facilities. Figure 27-3 uses data from the International Energy Agency to show that on average Latin America (includes Central, South America plus Mexico) has on average a 60% of electricity provided by hydropower facilities in contrast to a less than 20% for the world and for any other region for that matter. Looking a some specific countries in the region it can be seen that in general hydropower proportion of total electricity production is over 40% and in some cases is near or close to 80% (cases of Brazil and Costa Rica for example).

[INSERT FIGURE 27-3 HERE
Figure 27-3: Title ? Source: http://www.iea.org/stats/]

It is not a coincidence based on these previous statements that there have been a series of studies which have been devoted to analyze the potential impacts of climate change on hydropower generation capacity in the region. In Central America the most prominent example is the study by Maurer et al. (2009) who studied future hydrologic conditions for the Lempa river basin, the largest river system in Central America covering portions of three countries: El Salvador, Honduras and Guatemala and holding major hydroelectric facilities. The results of the modeling work which includes an uncertainty analysis show a reduction in firm hydropower capacity of 33% to 53% by 2070-2099. A similar loss is expected for the Sinu-Caribe basin in Colombia were despite a general projection of increased precipitation, losses due to evaporation enhancement reduces inflows to hydroelectric systems reducing electricity generation up to 35% compared to base conditions (Ospina et al., 2009). Overall reductions in hydropower generation capacity are also expected in Chile for the main hydroelectric generation basins: Maule, Laja and Biobio (ECLAC, 2009; Stehr et al., 2010) and also in Argentina in the Limay basin (Seoane and Lopez, 2007). Ecuador on the other hand faces an increase in generation capacity associated with an increment in precipitation on its largest hydroelectric generation basin, the Paute basin (PACC, 2009; Buytaert et al., 2010)**.** The situation in Brazil, the country with the largest installed hydroelectric capacity is complex (Freitas and Soito 2009). According to de Lucena et al., (2009) the systems in the south of the country (most significantly the Parana River system) could face a slight increase in energy production under an A2 scenario. However, the rest of the country's hydroelectric system and specially those located in the North East region would face a reduction in power generation reducing the reliability of the whole system.

[a summary table with previous results will be included]

An obvious implication of the above mentioned impacts is the need to find replacement for the energy lost due to climate change impacts. In this regards, a typical adaptation measure would be an increase in other forms of generation. Least cost adaptation measures have been studied for the Brazilian case (de Lucena et al., 2010) with results implying an increase in natural gas and sugarcane bagasse electricity generation in the order of 300 TWh, increase in operation costs in the order of 7 billion USD annually and 50 billion USD approximate in terms of investment costs by 2035. In the case of Chile ECLAC (2009) assumed that the loss in hydropower generation would be compensated by the least operating cost source available (not used probably at full capacity) which is coal-fired power plants. In this case the amount of electricity that needs to be replaced in average for the 2011-2040 period is around 18 TWh of electricity or little over 10% of actual total hydropower generation capacity in the country. This on implies on the other hand an increase on operating costs of the order of 100 million USD annually and an increase in the order of 2 MTCO2e (total emissions from the electricity generation subsector in the country are around 25 MTCO2e in 2009).

There are other implications not as obvious as the ones presented before. For example, changes in the seasonality of inflows to hydropower generation systems such as those projected for Peru (Juen et al, 2007), Chile (ECLAC, 2009) or Argentina (Seoane and Lopez, 2007) could have serious implications on the relation between different water users within a basin. In Chile for example, the loss in snowpack accumulation due to temperature increase could reduce significantly spring and summer streamflows affecting water supply to agriculture irrigation that depends on the naturally flowing water through that period. This could introduce future economic and social conflicts on the relation among these two sectors that share water resources consumption within a basin. It is interesting to note also that in those regions which are projected to face an increase in streamflow and associated generation capacity such as Ecuador or Costa Rica also share difficulties in managing deforestation and erosion which limits the long term usage of these system via sedimentation. In these cases it is important to consider these effects in future infrastructure planning and also enhance the already started process of recognizing the value of the relation between ecosystem services and hydropower system operations (PACC, 2009; Leguia et al., 2008). See more on this issue in Case Study 6.3.

27.5.2. Land-Use Change

The main land uses responsible for deforestation in tropical and subtropical Latin America are: smallholder agriculture, cattle ranching, soybean production and oil palm plantations. More than 27 million hectares of the world's humid tropical forests were cleared between 2000 and 2005, and Latin America showed by far the highest deforestation rates (60% of total tropical deforestation, Hansen et al 2008). Conversion to agricultural lands is the main driver of tropical deforestation (Geist and Lambin 2002). Although deforestation has been attributed to smallholders ("slash and burn" rotational agriculture), this trend has drastically changed in recent decades. Today, large-scale agriculture is the main cause of deforestation in South America (FAO 2001).

Regarding small-holders, some types of rotational agriculture are practiced by native populations (Freire 2007), but the largest area of forest conversion by small farmers is associated with families who migrate in search of land. For example in the Peruvian Amazon Oliveira et al (2007) found that less than 9% of the deforestation occurred between 1999 and 2000 was observed in Indigenous territories.

Livestock production is the predominant land use in deforested areas of tropical and subtropical Latin America (Hecht 1993, Grau et al 2005, Wassenaar et al, 2007). More than 2/3 of the total deforested areas in Colombia (Etter et al 2006 regional patterns paper) and in the Brazilian Amazon (Fearnside 2005, Nepstad et al 2006) are converted to cattle ranching. Forest conversion to pasture for livestock is also the major land use in lowland in Bolivia (Kileen et al 2008).

Soybean production is the most recent significant type of agricultural expansion in forest frontier areas of tropical and subtropical South America (Nepstad et al 2006, Killeen et al 2008, Grau et al 2008). Brazil and Argentina are the second and third soybean world producers respectively, and jointly produce more than 50% of the soybean global consumption (Soystats 2009) (www.soystats.com). Soybean cultivations started to be established savanna and grasslands areas of Argentina and Brazil, but the last decades showed gradual expansion to forest areas such as El Chaco region in Argentina, the lowlands in Bolivia and Southern Amazonia (Fearnside 2001, Grau et al 2005, Grau and Gasparri 2005).

Oil palm is the most significant industrial crop linked to deforestation in tropical South America. Its magnitude is still very small compared with soybean but it is still considerable and expected to increase due to increasing demands in the region for biofuels, and for palm oil from Asia. Colombia is the largest oil palm producer in Latin America and the fourth in the world with almost 300,000 ha planted (Fedepalma 2009, http://www.fedepalma.org/). It is predominantly planted in medium and large farms: 35% of the oil palm plantations are smaller than 500 ha and about 32% of the plantations are larger than 2000 ha. The main forest regions in South America where oil palm has recently expanded are the Chocó region in Colombia (Restrepo 2004, Forero 2009) and the Sucumbios region of Ecuador. Oil palm production is also important on Brazil (with 75% of the area in the state of Bahia) and emerging in the Amazonian region of Peru mainly in the regions of San Martin and Ucayali.

27.5.3. Biodiversity Loss and Payment for Ecosystem Services

Payment for ecosystem services (PES) consists of schemes of direct payment for landowners and include services such as regulation of freshwater flows, carbon storage, provision of habitat for biodiversity, and scenic beauty (Wendland et al. 2010). Since the ecosystems that provide the services are often privately owned, policies should aim at supporting land-owners to maintain the provision of services over time (Kemkes et al. 2010). PES are generally perceived to be the most direct way to stimulate the provision of a given ES. Albeit with few concrete examples, PES has received much recent attention (Börner et al. 2007; Wunder et al. 2008). Costa Rica was one of the first countries to implement a national PES scheme to manage ES such as biodiversity, soil erosion, water flow, and forest carbon stocks (Pagiola 2007). Effectiveness, cost-effectiveness, and equity effects of these pioneering projects have yet to be comprehensively assessed; and the context-specific factors that are likely to influence these indicators of MO performance not yet been identified or carefully studied (Pagiola et al. 2005; Wunder 2007). In the Andes, watershed PES schemes are mushrooming, partly because transaction costs of reaching agreements are lower in well defined watersheds with up-stream ES modifiers and downstream ES users (Southgate and Wunder 2007).In the Amazon, few PES-like schemes exist, and large-scale applications are limited by poor information on tenure rights of ES providers.

Montagnini & Finney (2011) present examples of PES in Colombia, Costa Rica and Nicaragua to show it can be a tool to finance reforestation, restoration, conservation and changes in land use that enhance rural development. Further, PES programs can induce positive attitude changes in farmers. However, based on examples from Ecuador and Guatemala, Southgate et al. (2010) argue that uniformity of payment for beneficiaries can create inefficiency if some recipients would accept less compensation in return for adopting conservation measures, or if households where environmental gains are greater are not offered something more than the prevailing payment. Table 27-1 lists examples of PES schemes in Latin America.

[INSERT TABLE 27-1 HERE
Table 27-1: Government-funded PES successful schemes in Latin America.]

27.6. Data and Research Gaps

[to be included in the next version]

27.8. Conclusion and Perspectives

[to be included in the final version]
(Perspectives on increasing adaptive capacity for agriculture, including agricultural improvements to induce less pressures from expanding agricultural frontiers, and on water resources uses; discussion on risks for ecosystems throughout the continent and highlight different strategies for preservation across many eco-climatic gradients; discuss difficulties, gaps of knowledge and perspectives of sustainable pathways for natural resource exploitation in South America on the face of climate and land use changes; include a discussion on limits to adaptation in the region, that is, if global warming exceeds thresholds (e.g., 4 C)).

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Table 27-1: Government-funded PES successful schemes in Latin America.

Countries	Level	Start	Name	Beneficiaries	Area protected	Reference
Brazil	Sub-national (Amazonas state)	2007	*Bolsa Floresta*	2,702 families by Sep. 2008	12 protected areas	Viana (2008)
Costa Rica	National	1997	FONAFIFO fund	*	650,451 ha by 2009	FONAFIFO (2010), Daniels et al. (2010)
Ecuador	National	2008	*Socio-Bosque*	60,720 people by Oct. 2010	527,503 ha	DeKoning et al. (2011)
Mexico	National	2003	Payment for Hydrological Environmental Services of Forests	*	*	Munõz-Piña et al. (2008)
Guatemala	National	1997	Programa de Incentivos Forestales, PINFOR	All citizens with legal land title who plant or protect forest.	*	*

*still looking for this info.

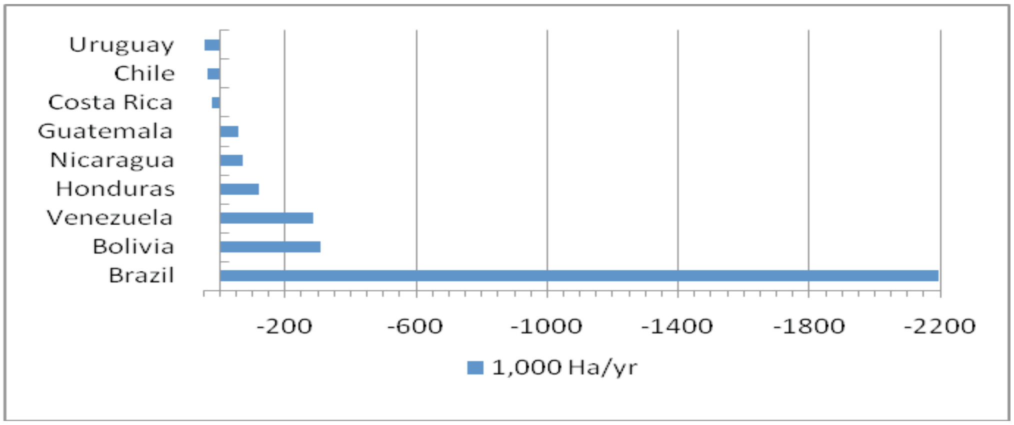

Figure 27-1: Area deforested per year for selected countries in Central and South America (2005-2010). Notice three countries listed with a positive change in forest cover (prepared with data from FAO, 2010). Observed rates are: Uruguay 2.79%, Chile 0.23%, Costa Rica 0.90%, Guatemala -1.47%, Nicaragua -2.11%, Honduras -2.16%, Venezuela, -0.61%, Bolivia -0.53%, Brazil, -0.42%).

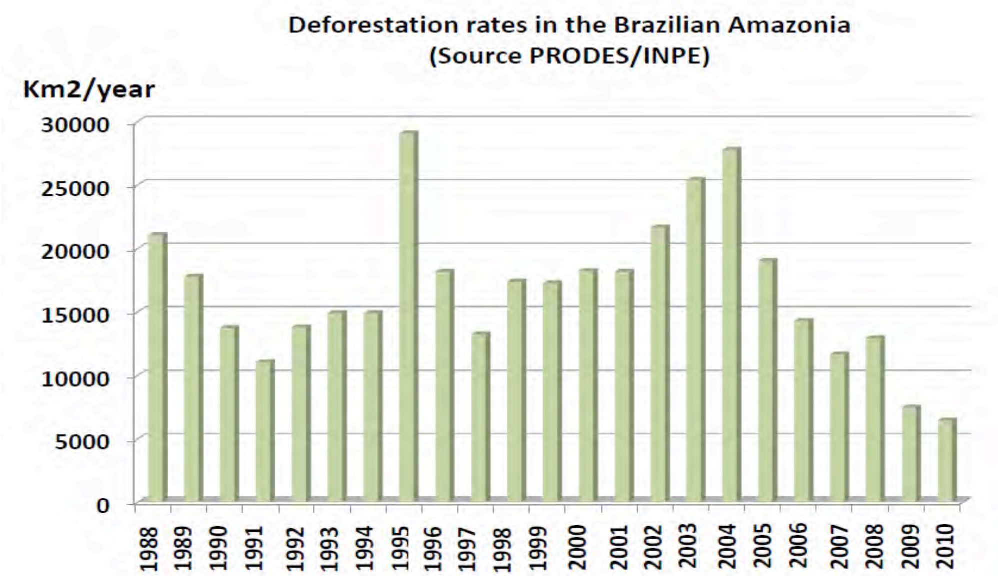

Figure 27-2: Deforestation rates in the Brazilian Amazonia (Km2/year) as measured by the PRODES INPE project (www.inpe.br/prodes).

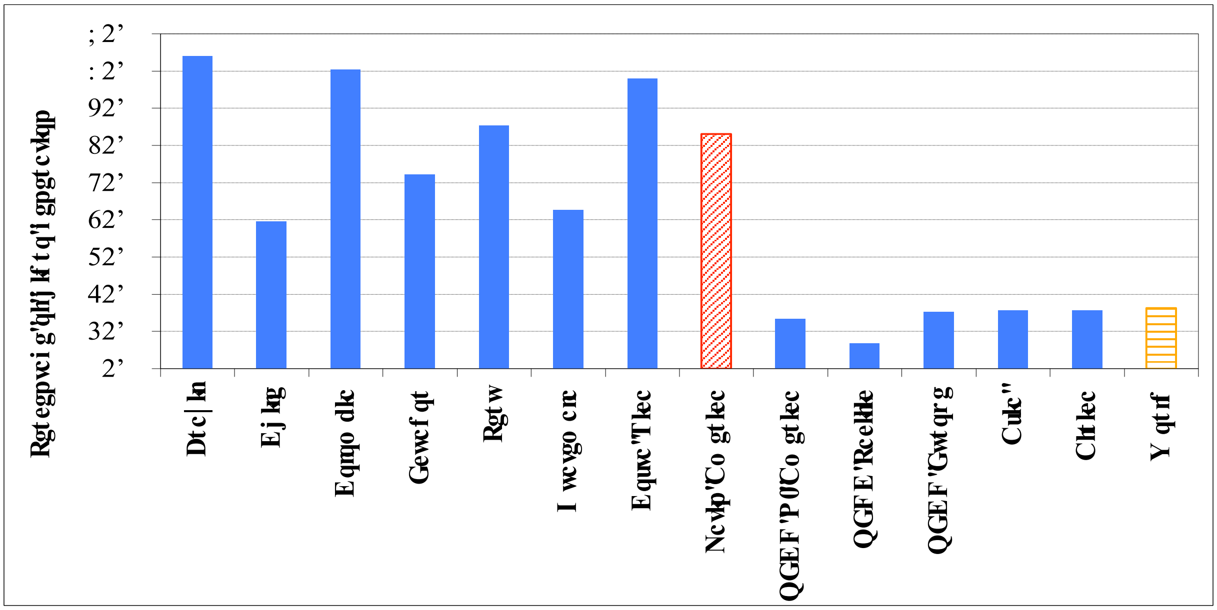

Figure 27-3: Title ? Source: http://www.iea.org/stats/