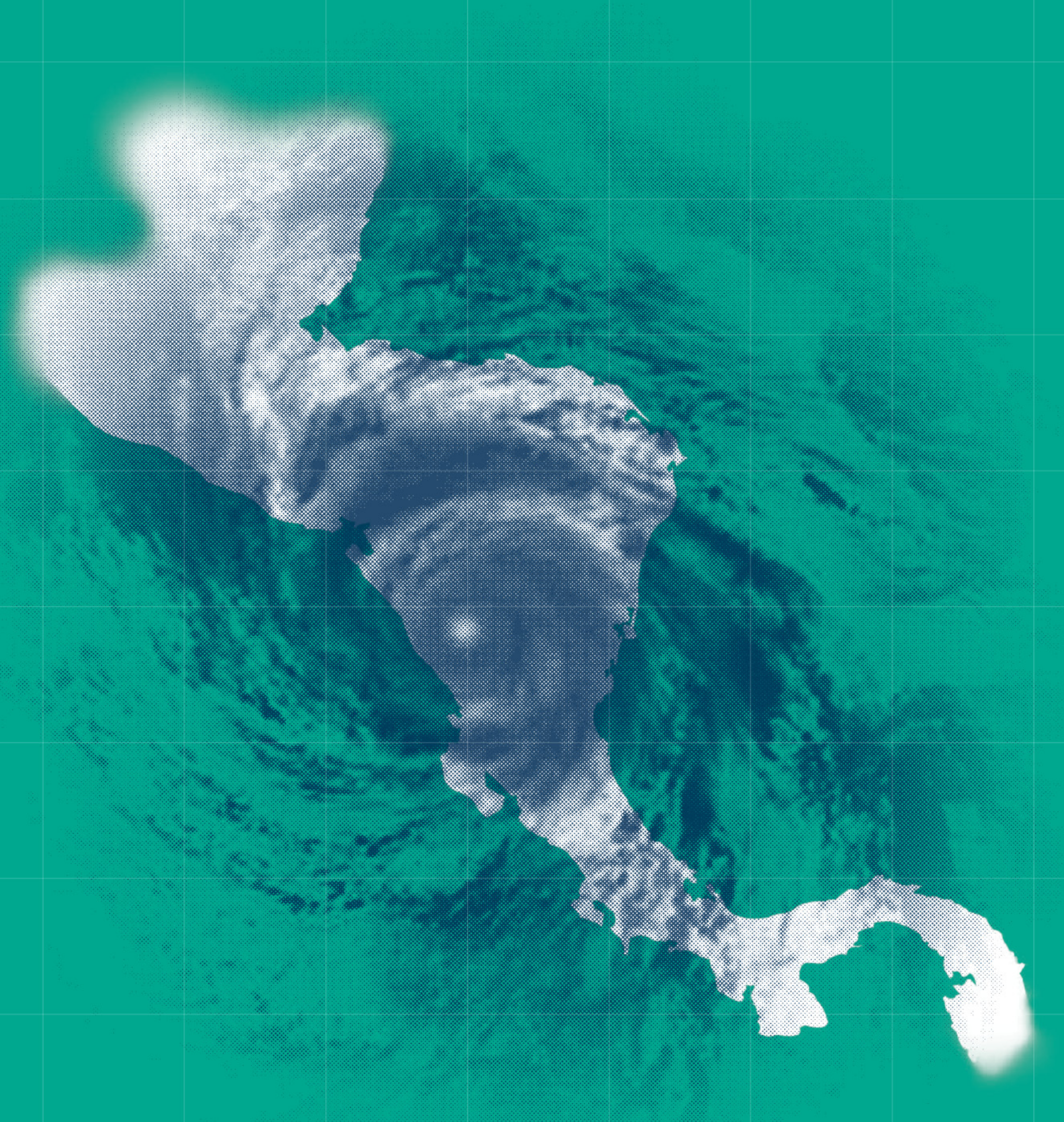
The Economics of Climate Change in Central America

Summary 2012



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The Economics of Climate Change in Central America: Summary
2012

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ABBREVIATIONS AND ACRONYMS

ACE	Attribution of Climate-related Events
ACL	American cutaneous leishmaniasis
ADD	Acute Diarrhoeal Disease
ARI	Acute Respiratory Infection
ATL	American tegumentary leishmaniasis
BPI	Biodiversity Potential Index
CAC	Central American Agricultural Council
CATIE	Tropical Agricultural Research and Training Centre
CAZALAC	Water Center for Arid and Semi-arid Zones of Latin America and the Caribbean
CCAD	Central American Commission on Environment and Development
CCSI	Climate Change Severity Index
CDM	Clean Development Mechanism
CEL	Hydroelectric Executive Commission of Rio Lempa
CEPREDENAC	Coordination Centre for the Prevention of Natural Disasters in Central America
CL	Cutaneous leishmaniasis
COMISCA	Council of Health Ministers of Central America and the Dominican Republic
COP 15	15th Conference of the Parties to the United Nations Framework Convention on Climate Change, Copenhagen, 2009
COP 16	16th Conference of the Parties to the United Nations Framework Convention on Climate Change, Cancun 2010.
COP 17	17th Conference of the Parties to the United Nations Framework Convention on Climate Change, Durban 2011
COPECO	Honduran Permanent Commission for Contingencies
COSEFIN	Council of Ministers of Treasury/Finance of Central America, Panama and the Dominican Republic
CU	Coordinating Unit of the Economics of Climate Change in Central America initiative
DANIDA	Danish International Development Agency
DCL	Diffuse cutaneous leishmaniasis
ECCCA	Economics of Climate Change in Central America initiative
ECLAC	Economic Commission for Latin America and the Caribbean
EHE	Extreme hydro-meteorological event
EIP	Extrinsic Incubation Period
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
FONAFIFO	National Forest Financing Fund of Costa Rica
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GLOBIO3	Global Biodiversity Model
GM-UNCCD	Global Mechanism of the United Nations Convention to Combat Desertification
HD	Haemorrhagic Dengue
HLZ	Holdridge Life Zone
HURDAT	Hurricane and storm registry
ICGES	Gorgas Memorial Institute for Health Studies, Panama
IHP	International Hydrological Programme
IMN	National Meteorological Institute of Costa Rica

INDE	National Electrification Institute of Guatemala
INSIVUMEH	National Institute of Seismology, Volcanology, Meteorology and Hydrology of Guatemala
INSMET	Meteorological Institute of Cuba
INSP	National Institute of Public Health of Mexico
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
LUC	Land-use change
MA	Malaria
MARENA	Ministry of Environment and Natural Resources of Nicaragua
MARN	Ministry of Environment and Natural Resources of El Salvador
MCL	Mucocutaneous leishmaniasis
MINAET	Ministry of Environment, Energy and Telecommunications of Costa Rica
MINSA	Ministry of Health of Costa Rica
MSA	Mean Species Abundance
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
PACT	Protected Areas Conservation Trust, Belize
PAHO	Pan American Health Organization
PINEP	Incentives Programme for Small-Scale Owners of Land Suitable for Forestry or Agroforestry of Guatemala
PINFOR	Forestry Incentives Programme of Guatemala
RTC	Regional Technical Committee of the ECCCA initiative
SICA	Central American Integration System
SIECA	Secretariat for Central American Economic Integration
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
UKAID	Department for International Development, UK Government
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VBD	Vector-Borne Diseases
VL	Visceral leishmaniasis
WAPPO	Water and Power Potential Programme
WCRP	World Climate Research Programme
WHO	World Health Organization
WMO	World Meteorological Organization

FOREWORD

One could consider climate change to be a phenomenon that will only have an effect in the distant future, but the growing impacts of extreme weather events such as Tropical Depression Twelve-E and intensifying droughts demonstrate that immediate action must be taken in the face of climate disturbances. The pressure of existing social and economic issues as well as budgetary constraints aggravated by the global recession could be wielded as arguments for postponing the implementation of much-needed measures. However, current reality requires that reconstruction measures be different than in the past in order to reduce vulnerability and cost of future extreme events, and tackle the threat of climate change.

We recommend promoting **inclusive and sustainable adaptation strategies** that integrate measures to reduce poverty and vulnerability along with measures to adapt to climate change and transition towards more sustainable, low-carbon economies. Thus, we could see the current global economic recession and potential risks of climate change as opportunities to carry out an in-depth review of the productive specialization of economies, including modalities of participation in regional and global markets, the growing dependence on hydrocarbon consumption—with the associated costs of importation, pollution, and harm to public health—and the degradation of forests and other ecosystems that provide a multitude of products and services.

This opportunity requires changes in infrastructure standards; protection of river basins and natural coastal barriers such as mangroves; improvement in water-management; changes in the design and location of households, communities and social infrastructure, etc. It also implies the development of a strategic vision to maximize the benefits and minimize the cross-sectoral costs of adaptation and mitigation measures, by integrating them in the development agenda. Ultimately, it requires special attention to all forms of inclusion and sustainability.

Climate change presents a series of multi-sectoral challenges that have to be tackled jointly by the public and private sectors, citizens and civil organizations, academia, multilateral organizations and the international community. We reiterate our commitment to continue collaborating with our Central American partners in this great endeavour.

Hugo E. Beteta

Director, Subregional Headquarters, ECLAC/Mexico

KEY MESSAGES

Central America is already one of the regions of the world most exposed to climate change. As a narrow isthmus between two continents and the Pacific and Atlantic Oceans, it is frequently affected by droughts, cyclones and the El Niño-Southern Oscillation (ENSO). Climate change is exacerbating socioeconomic vulnerabilities in Central America and will increasingly affect its economic progress, given that the factors of most importance to production activities, such as agriculture and generation of hydroelectric power, depend on the climate. The region has valuable natural and cultural assets that need to be preserved and valued for their contribution to the development of current and future generations. The ecosystems and abundant biodiversity of Central America provide many products and services, including pollination, pest control, and regulation of humidity, water flow and local climate; however, these are being harmed by unsustainable development. The population of the region is relatively young and has great diversity in terms of culture, ethnicity and lifestyle, and is a valuable resource that needs greater recognition and investment. These valuable assets can contribute significantly to the response to climate change, but is also likely to be very vulnerable to its effects. In fiscal terms, this issue is a contingent public liability that will increasingly affect public finances, which are already under great pressure due to the impact of a growing number of extreme weather events such as hurricanes, intense rains and floods. At the same time, it is estimated that Central America produces only a minimal portion of global greenhouse gas (GHG) emissions (less than 0.3% of emissions without land-use change, and less than 0.8% of net total emissions[1]).

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extreme weather events. Vulnerability is a function of the character, magnitude, and rate of climate change to which a system is exposed, and of the sensitivity and adaptive capacity of that system" (IPCC, 2004). The combination of factors that affect vulnerability and exposure represents a further challenge to development efforts. It would be advisable to have standardized indicators for making decisions and setting priorities at both the national and international level, since the Millennium Development Goals and conventional variables used to categorize less developed countries (LDCs) might not accurately reflect exposure to, and risks of, climate change, or appropriate national responses.

The Global Climate Risk Index prepared by *German Watch* contributes to these efforts by qualifying the impact of extreme weather events (storms, floods, temperature extremes, heat waves and cold snaps) in a ranking of 183 countries in which the lowest ranked country is the most vulnerable. Results for the period 1992-2011 show that Honduras was the country most impacted;

[1] Estimates are based on national inventories from 2000, IPCC global figures (2007b) and the CAIT database of the *World Resources Institute*. It is important to note the high degree of uncertainty related to land-use change emissions.

Nicaragua, third-most; the Dominican Republic, tenth; Guatemala, eleventh; El Salvador, fifteenth; Belize, sixteenth; and Costa Rica, sixty-second. Due to the increase in extreme weather events in recent years, the same indicator for the period 2004-2011 shows that countries in the Central American region often place in the top ten places of risk: Dominican Republic, second in 2004; Guatemala, first, and Honduras, seventh in 2005; Nicaragua, third in 2007; Belize, ninth in 2008; El Salvador, first in 2009; Guatemala, second and Honduras, fifth in 2010; and El Salvador, fourth and Guatemala, ninth in 2011 (Harmeling, 2012).

Appropriate indicators for making decisions on climate change can be developed using mechanisms from the United Nations Framework Convention on Climate Change and the Rio+20 Conference agenda, which was established in the resolution, "The Future We Want". This resolution outlines a process for establishing sustainable development goals. Given this global agenda and the need to create national public policies, it is necessary to continue estimating the physical, economic and social impacts of climate change, as well as its partial responsibility for extreme weather events and cumulative processes (such as increased aridity), and to analyze the costs and benefits of different responses. It is advisable to have disaggregated data at the sub-national level in order to identify the populations, sectors and regions that need assistance most urgently in each country's adaptation efforts; this will prevent the situation of these regions from being lost in national averages. The analysis carried out by The Economics of Climate Change in Central America (ECCCA) initiative over the last year and a half seeks to respond to the greater awareness of these challenges in Central America, reflected in presidential and ministerial statements.

In its 2007 Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) notes that the frequency of intense rainfall has increased over most land areas, consistent with the effects of global warming and an increase in water vapor. The report states that there is medium confidence that anthropogenic influence has contributed to the intensification of extreme precipitation on a global scale and of droughts in some areas, including Central America, due to a decrease in rainfall and/or an increase in evapotranspiration. The report warns that a set of events that, individually, are not considered very extreme, can have a cumulative effect that can give rise to droughts and landslides.

According to the EMDAT database, 291 major extreme events were recorded in Central America between 1930 and 2011. It is estimated that there has been a 7% annual increase in the number of disasters over the last three decades, compared to the 1970s. The most frequent events are floods, storms, landslides and mudslides (86% of total events recorded), followed by droughts (9%). Furthermore, there have been multiple events on a smaller-scale whose effects have not been assessed.

A possible change in the spatial distribution of tropical cyclones has been observed during recent decades. Previously, the most exposed regions included almost the entire Atlantic coast, all of Belize, a large part of Honduras and Nicaragua, and northern Costa Rica. However, hurricanes originating in the Caribbean tend to push the Intertropical Convergence Zone (ITCZ) towards northern Central America, which causes storms (several days of intense rainfall or significant accumulation), floods and landslides in areas that are larger than those affected directly by the hurricanes, as occurred with Hurricane Mitch. The last few decades have also seen storms and hurricanes making landfall via the Pacific Ocean, modifying their usual trajectory by which they made landfall higher north.

Tropical depressions and storms that do not become hurricanes are now more intense; one example is Tropical Depression 12-E, which originated in the Pacific and took a great toll on El Salvador and parts of Guatemala, Honduras and Nicaragua. It is of interest to note that short events (lasting less than two days) coming from the Atlantic Ocean have become increasingly frequent, particularly since 1960. The frequency of intense rainfall has increased in some areas of the region, and it would be advisable to analyze whether this increase is related to climate change. The frequency of storms of moderate duration has also increased since 1980, but has historically fluctuated in a cycle of approximately three decades. The relationship between the frequency of these events and climate change may become clearer once it is determined whether or not this pattern changes its historic oscillation in the coming decades.

The evidence of a relationship between the intensity of these events and climate change is stronger than ever. It is estimated that the oceans have absorbed about 20 times more heat than the atmosphere during the last half century, causing higher temperatures in shallow and deep waters, which in turn contribute to the increased intensity of tropical cyclones. This hypothesis is based on research that establishes a positive relationship between both of these phenomena. The surface temperatures of the Pacific Ocean and the Caribbean Sea, whose waters affect the climate of Central America, have increased over the last hundred years; historical records indicate that the area of the Pacific Ocean associated with ENSO (20N–20S and 90W–120W) has experienced a temperature rise in this century and that the Caribbean has seen an acceleration in warming since the mid-nineties (Jury, 2011). A review of international literature suggests that the intensity of hurricanes could increase by between 5% and 10% during this century (ECLAC, CCAD/SICA, UKAID, DANIDA, 2011a).

Another line of analysis is based on the laws of thermodynamics, which indicate that elevated temperatures lead to higher rates of evaporation and evapotranspiration, a greater amount of water vapor in the atmosphere, and an acceleration or destabilization of the water cycle. Stott, of the Hadley Centre, has estimated that for every 1°C increase in temperature there is a 7% average global increase in atmospheric humidity, which could lead to more intense rainfall events. Historical climatology indicates that Central America has seen an average temperature rise of approximately 0.5°C over the past 50 years; under the less pessimistic climate change scenario (B2), temperatures could rise during this century by 2.5°C on average, relative to the 1980-2000 average. Under the more pessimistic climate change scenario (A2), which supposes a continuation of the current trend of rising emissions, there could be an average temperature increase of 4.2°C (ECLAC, CCAD/SICA, DFID and DANIDA, 2011a). Furthermore, ocean surface temperature could be a transmission factor for climate change, bringing about more intense rainfall events.

International experts believe that analyzing the role of climate change in hydro-meteorological events is a very complex task involving considerable uncertainty. The IPCC suggests examining changes in the mean and variance, or the probability distribution of precipitation volume, or a combination of these (IPCC, 2011). In Central America, an initiative has been undertaken to analyse precipitation variability using daily records of accumulated rainfall from the main meteorological stations for the past four decades. This initiative has analysed daily and annual accumulated precipitation considering ENSO periods, number of days of rain, extreme precipitation events, and accumulated rainfall from storms of short, moderate and long duration. To date, analysis of selected stations in El Salvador, Honduras and Guatemala has been carried out. Although the rest of the countries of the region still require analysis, there is already evidence from some of the stations

analysed of increased variability and increased frequency of intense rains, especially in areas of the Pacific.

The possible pattern of future precipitation is less certain. Under the less pessimistic scenario (B2), precipitation would decrease by 3% in Panama; 7% in Guatemala; between 10% and 13% in Costa Rica, Belize, El Salvador and Honduras; and 17% in Nicaragua, with an average regional decrease of 11%. Under the more pessimistic scenario (A2) there would be an 18% decrease in precipitation in Panama, 35% in Nicaragua and between 27% and 32% in Costa Rica, Belize, El Salvador, Guatemala and Honduras, with an average regional decrease of 28%. However, even though a smaller decrease in precipitation is expected under scenario B2, rising temperatures will lead to greater evapotranspiration and result in reduced availability of water, especially in the second half of the century, thereby affecting ecosystems, agriculture and hydroelectric power generation. Under the more pessimistic scenario (A2), the repercussions would be greater. Analysis of aridity and dry months shows that temperature and precipitation levels for the period 1950-2000 generate an aridity index value of 1.6 for Central America, with variations between the geoclimatic region of the Western Highlands of Guatemala, which is more humid (aridity index value of 1.96), and the more arid regions of the Dry Corridor of Central America (aridity index values of between 0.91 and 1.25). It is estimated that the region could experience conditions associated with an aridity index value of 1.4 in the less pessimistic scenario (B2) and 1.2 in the more pessimistic scenario (A2), with a prevalence of aridity conditions similar to those in the most arid areas of the Dry Corridor in the 1950-2000 period.

Central America is a privileged region in terms of availability of water, but distribution of this resource between countries, the Pacific and Atlantic coasts and the population is very unequal, and there is significant intra- and inter-annual variation. This variation leads to alternating periods of severe droughts and floods. In a scenario that accounts for population growth but does not involve water-saving measures, demand for water could grow by almost 300% by 2050 and by more than 1600% by 2100, the equivalent of a water-use intensity of 36%—without considering climate change. With climate change factored in, this figure could reach 140% under scenario B2 and more than 370% under scenario A2 if measures to adapt and save water are not implemented. These levels would be much higher than the 20% accepted internationally as the threshold for water stress. Scenario A2 suggests conditions similar to those of current-day Egypt and some countries in the Arabian Peninsula.

Water availability is related to both inter-annual precipitation patterns and geographical differences in precipitation. During the period 1950-2000, the Pacific coast experienced a dry season and a rainy season, with rainfall peaking in June, then decreasing in July and August and reaching another peak again in September and October, usually higher than the one in June. By contrast, some Atlantic regions had no dry months; however even in these cases, precipitation began to increase in April, following different intermediate patterns until diminishing again during November and December. It is estimated that under scenario B2, the rainy season could start earlier in the year, with more intense rainfall in the early stages of the season. It is estimated that precipitation would decrease following the period known as “dog days”, especially during the second half of the century, resulting in some countries moving away from their bimodal weather pattern. Under scenario A2, it is estimated that the bimodal pattern of precipitation could be exacerbated in the coming decades with an increase in the intensity of both rainy periods and dog days. Afterwards, precipitation at the beginning of the season would gradually decrease, leaving only one precipitation maximum between

October and November. Costa Rica and Panama would be exceptions and might experience an increase in precipitation at the beginning of the season during the coming decades; subsequently, these countries might experience a decrease in precipitation nearing historical lows, with a relatively stable pattern from June to November.

These scenarios of potential changes in temperature, annual precipitation and intra-annual patterns suggest greater risks and uncertainty for productive activities such as hydroelectric power generation. The combined effect of the rise in temperature and the changes in precipitation will affect evapotranspiration in river basins, and thus their river flows and evaporation in hydroelectric reservoirs. A pilot study of two hydroelectric plants (Chixoy in Guatemala and Cerrón Grande in El Salvador) estimates that this chain of effects would result in reductions in electricity generation of over 20% in both plants by 2020 under the more pessimistic scenario (A2) compared to the average generation achieved during reference periods (1979–2008 for Chixoy and 1984–2009 for Cerrón Grande). By 2050, the reductions would be greater than 40% in both plants, and by the end of the century, these figures would be more than 80% for Chixoy and 70% for Cerrón Grande. Under the less pessimistic scenario (B2), there could be an increase of between 4% and 6% in electricity generated in both plants by 2020, relative to the reference period. However, from 2020 onwards, estimates are negative, with a 26% decrease for Chixoy and a 17% decrease for Cerrón Grande by 2100. It is recommended that a more detailed analysis of possible changes in the next two decades be carried out, and that the operating models of the reservoirs be reviewed. In both reservoirs, the filling period currently lasts five months, from June to October (i.e. the rainy season). The operating models could be modified so as to adapt to a greater variability in rainfall in the short term and to potential changes in the intra-annual rainfall pattern and the annual accumulated volumes, especially under the more pessimistic scenario (A2).

The agricultural sector—another sector that is vulnerable to climate change—represents 18% of total regional GDP including agro-industry. According to initial regional estimates, maize production could increase in the short term with yields of slightly more than two tons per hectare, but then would decline, possibly falling to 1.4 tons per hectare around 2100 under the more pessimistic scenario (A2) if no adaptation measures are taken. Average bean yields may decline from more than 0.7 to less than 0.1 tons per hectare. Rice production could also fall, from the historic average of 3.5 tons per hectare to between 1 and 2 tons per hectare towards the end of the century. It is important to remember that maize, beans and rice are essential sources of calories and protein for large segments of the Central American population. Although bean production represents less than 4% of agricultural GDP, when combined with maize or rice, it is an invaluable nutritional source of protein and iron for a large segment of the population. Depending on the country, small-scale farmers with low incomes retain a significant part of their basic grain production for on-farm consumption. Climate change will have a significant impact on food security for rural producers, as it would reduce food production and direct access to food, as well as increase the price and scarcity for consumers, depending on the availability of compensatory imports. Therefore, the implications of climate change for food security and poverty are serious and need to be studied in more depth.

Central America is home to 7% of the planet's biodiversity due to its great geological, geographic, climatic and biotic variety. In a scenario of land-use change (LUC) without climate change, the Potential Biodiversity Index (PBI) would decrease by approximately 13% during the current century, with most of the decrease happening by 2050. With climate change, the PBI would

decline by 33% and 58% by 2100 under scenarios B2 and A2 respectively. Guatemala, Nicaragua, El Salvador and Honduras would be the hardest hit, with PBI reductions of between 70% and 75% under scenario A2. To complement this analysis of biodiversity, another study on Central American forests has been carried out using the Holdridge Life Zones (HLZ) classification. According to this method, forest cover would decrease in a scenario of land-use change without climate change, from approximately 28.5 million hectares to 16.3 and 16.9 million hectares by 2050 and 2100 respectively. However, the proportions of the six predominant HLZs in Central America would not change significantly. It is estimated that in the land-use change with B2 scenario, the tropical wet forest would become more predominant than it is currently, rising from 44% of total area in 2005 to just over 70% by 2100. By contrast, in the land-use change with A2 scenario, the tropical dry forest would see the largest increase in surface area, increasing from 11% to 39% of total area. These two HLZs would account for almost 84% of the total natural forest cover in this scenario, and the other humid forest zones would suffer significant losses.

Therefore, both scenarios suggest different HLZ patterns, one towards drier forest ecosystems (A2) and the other toward more humid ones (B2). In both scenarios, it is estimated that there will be an increase in humid areas by approximately 2020 and a decrease in life zone diversity over the decades. It is estimated that there will be variations between countries: Belize's tropical wet forest would account for 90% of the total area in 2100 under scenario B2, but under scenario A2, tropical dry forest could account for 44%. Costa Rica would experience more homogeneous patterns in all three scenarios (LUC, B2 and A2) and would maintain greater HLZ diversity. This study evaluates the temperature and precipitation conditions associated with the various HLZs, but it remains to be analyzed whether their life forms could adapt, given the speed of the projected changes in precipitation and temperature, coupled with the pressure of land-use changes. The results confirm that reducing deforestation and making progress in the protection and recovery of natural ecosystems are themselves development challenges, and indicate that climate change, especially under the more pessimistic scenario (A2), could bring greater loss of tropical forests and the services that their ecosystems provide.

Of the approximately 41 million inhabitants of Central America, two-thirds live in conditions that combine poverty and poor sanitation and health services (FAO-ETEA, 2008). These adverse conditions make the population vulnerable to climate change, since poverty-related diseases such as malaria and dengue are also associated with changes in the climate (Noji and Toole, 1997). Furthermore, these populations face the direct and indirect effects of extreme events on health, including serious secondary effects brought about by floods, crop destruction and relocation of affected persons to overcrowded and unsanitary spaces. Due to its varied topography and proximity to two oceans, Central America houses a wealth of ecological niches that favour the transmission of diseases caused by changes in the climate.

With this challenge in mind, the Ministries of Health and the Council of Ministers of Health of Central America and the Dominican Republic (COMISCA) established the "Health and Climate Change" initiative in 2012 in order to produce more information on the possible impact of climate change on climate-sensitive diseases. ECLAC, the Pan American Health Organization (PAHO) and several expert institutions, such as the Gorgas Memorial Institute for Health Studies (ICGES) of Panama, the Meteorological Institute (INSMET) of Cuba, and the National Institute of Public Health (INSP) of Mexico, collaborate on this initiative. This initiative has made it possible to analyse the relationship between climate and incidence of the main diseases of Central America, including

dengue, malaria, acute diarrhoeal diseases, acute respiratory infections, Chagas disease, leishmaniasis and leptospirosis. A review has been carried out of analyses that report a correlation between the incidence of these diseases and temperature trends or events, such as rainfall or air pollution. The study identifies important efforts undertaken by the countries of the region to estimate climate variability and its influence on the health of its people. Some efforts examine climatic variables to explain the epidemiology of certain diseases, while others classify diseases according to the season (cold-hot, dry-wet) to explain their seasonality. Despite the progress made, if cross-sectoral adaptation measures are to be implemented, a strategic applied research agenda is needed in order to establish a relationship between temperature and precipitation and the incidence of diseases, and to develop scenarios of climate change and its impact on human health in the region.

The many direct and indirect impacts of climate change will exacerbate the different sources and forms of vulnerability for certain populations. Analysing these impacts requires taking into account the multiple dimensions of poverty and the ways in which it is experienced, using a method such as the "abilities and opportunities" approach taken by Amartya Sen (1999). This method requires an analysis of the ability of people to adapt to climate change, not only in terms of the financial, natural, educational and healthcare resources available to them, but also in terms of their ability to utilize these resources. The IPCC highlights that the problems resulting from climate change as well as their solutions are related to equity, as the countries that contribute least to GHG emissions are the most vulnerable due to their decreased capacity to adapt, and are therefore the ones that will suffer the greatest impacts of climate change (IPCC, WMO and UNEP). The Stern Report (2007) states that "climate change is a great threat to the developing world and a major obstacle to the continued reduction of poverty in its many dimensions". Therefore, it is suggested that adaptation strategies be integrated with those aimed at reducing poverty and inequality (ECLAC, 2009; IPCC, 2007; UNDP, 2007; AfDB and others, 2007).

Almost half of the population of Central America lives in poverty, and approximately a third lives in extreme poverty, which is particularly prevalent in rural areas. High levels of socioeconomic, ethnic and gender inequality persist, as reflected by several indicators, including the relatively high Gini index (0.53 in 2010); high rates of child and maternal mortality and morbidity; high levels of malnutrition and inadequate access to food, drinking water, health services, education, social security, capital and credit. A significant portion of the population that lives in poverty, especially in rural areas, depends directly on the environment for access to water, food, shelter, medicines and energy, among other needs. In some cases, the lack of capital and livelihood options leads to overexploitation of the environment by these populations. The general pattern of development and poor risk management has created a vicious cycle of human impoverishment and environmental degradation that will only worsen as climate change progresses.

Another segment of the population that lives in poverty—for example, those who live in marginal urban areas and/or those who are dependent on the informal economy—will be seriously disadvantaged when facing the economic instabilities that climate change could cause. This segment of the population accesses most of its goods and services through the market, and sectoral studies show that these communities could suffer a variety of impacts. A decrease and instability in availability of water and crop yields can affect labor markets, the supply and prices of basic goods, and migration to urban areas.

The challenge of social investment is related to the prevalence of informal work and the limited coverage of social protection in the majority of Central American countries. Only those employed in the formal sector have access to this coverage, which may include pensions, unemployment insurance and health services, among other services, although this is not true in all cases. Low per capita social spending in Central American countries (with the exceptions of Panama and Costa Rica, where social spending is relatively high) limits resilience and the ability to adapt. Recent decades have seen the implementation of conditional cash transfer programs for poor families in several countries to supplement income and encourage the use of basic health and education services. These programs have the advantage of focusing their coverage on poor households with children, adolescents, female heads of households, and the unemployed and economically inactive population (ECLAC, 2012). Cecchini and Madriaga (2011) state: "Some countries facilitate access to social services for the population in greatest need. However, one should not lose sight of the fact that these programs do not replace the roles of other policy instruments, and that their effectiveness depends largely on the presence of strong universal healthcare and educational systems." Strengthening the provision of these services remains a priority in the region and, in our current context, it is recommended that incentives for adaptation to extreme events and climate change be included.

Participation and political representation are important. Although the countries of the region have adopted democratic electoral systems, there is still much progress to be made in order for marginalised sectors, such as women, indigenous communities and people of African descent, to achieve effective participation in public decision making and consultation forums. In this vein, it will be necessary to carry out analyses with a focus on gender and ethnicity in order to more accurately determine differences in vulnerability and resilience in the long term, as climate change may worsen the cycle of intergenerational impoverishment.

In conclusion, there is mounting evidence that the impacts of climate change in Central America, in an A2-type scenario of rising emissions and global inaction, are significant and growing, with some degree of variation amongst the countries of the region. This evidence confirms the paradox that the developed countries that have polluted the most and have the greatest capacity to adapt face fewer impacts, while the countries that have contributed least to the problem are less resilient and face greater impacts. This result also lends weight to the idea that the cost of the impacts in a scenario of global inaction (particularly on the part of major emitting countries) would be higher than in a scenario with an equitable and inclusive international agreement that significantly lowers emissions. Such an agreement would have to have common but differentiated responsibilities, allowing the most exposed countries to implement adaptation and mitigation measures in the framework of sustainable and inclusive development.

Besides being ethically appropriate to act now rather than leave the problem for future generations, it is also more cost-effective from an economic standpoint. Research suggests that the cost of climate change impacts will be too high down the road if ambitious measures are not taken immediately. Research also confirms that climate change is the greatest market failure to date, as the market has not internalized the value of the climate as a global public good, nor properly accounted for its impact on society and environmental services. This failure indicates the need to go beyond economic valuations and make ethical decisions regarding the distribution of costs among generations, and value the needs of future generations. Ecosystems need to be similarly analysed, as they provide many environmental services that will be lost long before the market is able to

incentivise their appropriate management. Given that the aforementioned future scenarios are long-term and include various "layers" of analysis with uncertainty and methodological difficulties, the results should be interpreted as trends and relative magnitudes, not exact figures.

Climate change could be considered a phenomenon that will only have an effect in the distant future, and that cannot be addressed due to budgetary constraints, which have been worsened by the current global recession, as well as existing social and economic needs. However, the growing impacts of extreme events in the current period, such as Tropical Depression 12-E, demonstrate that urgent measures must be taken to reduce the growing threat of greater impacts and costs in the future. Current reality requires that reconstruction efforts be carried out in new ways, with changes in infrastructure standards, more efficient management of water resources, improved protection of forests, watersheds and natural coastal barriers such as mangroves, as well as changes in the design and location of homes, communities and infrastructure, among many other measures. Such investments would reduce vulnerability and the costs that would arise following future extreme events, and improve the ability to cope with the expected impacts of climate change.

It must be acknowledged that there will be limits to adaptation, and that irreparable damage and losses will occur, even with sufficient financing. Central American societies will need to avoid ad hoc strategies involving inertial logic that might respond to emergencies but heighten risks; solve problems in one sector at the cost of another, or address adaptation and sustainable development (including the mitigation of GHG emissions) separately, all of which is impractical for countries with limited investment and fiscal resources.

These challenges will have to be addressed now, at a time when the model of a self-regulating market is showing its limitations. Decisions must be taken to face the current global crisis, taking into account its long-term implications. As stated by Bárcena, humanity is living through a change of epoch, and significant structural changes on the scale of the industrial revolution are needed to address climate change and other externalities caused by industrialization and the hydrocarbon-based economy (ECLAC, 2010a). Other elements to consider are the significant population increase that will take place before stabilization in the second half of this century, the demographic transition and migration between countries and from rural areas to cities. The challenge of achieving inclusive development with a better quality of life and opportunities seems greater still if one considers the responsibility to future generations, i.e. intergenerational equality in terms of climate change. In addition, the coming decades will be characterized by the expansion of the knowledge-based society. The globalization of communications promotes deregulation, self-regulation and an increased flow of information, all of which promote democracy. However, this globalization has also contributed to the market becoming the central axis in the definition of identities. Dealing with the consequences of market self-regulation and excessive dependence on hydrocarbons requires greater collective awareness of global public goods, which in turn requires the transformation and strengthening of the processes and structures of global and national governability (ECLAC, 2010a; ECLAC, 2012).

With such a complex situation, it is advisable to formulate national, regional and international agreements to promote **inclusive and sustainable adaptation strategies** that combine measures to reduce vulnerability and poverty with measures to adapt to climate change and transition to more sustainable, low-carbon economies. This requires a strategic vision so that the

effect of potential co-benefits can be maximized between sectors and at the same time, any costs for a given sector resulting from measures in other sectors can be minimized. This same approach needs to be applied to actions focused on adaptation or on mitigation. Finally, this strategic vision regarding climate change should be integrated into national development plans. Ultimately, it implies special attention to inclusion and sustainability in their multiple dimensions. One example is a sustainable development agenda that includes making progress in energy efficiency and the protection and restoration of forests, which, if well-designed, could lead to co-benefits such as ecosystem adaptation, reduced emissions, and improved wellbeing and inclusion of populations living in poverty, including indigenous peoples.

In such a scenario, the current global economic recession and the risks of climate change can be seen as an opportunity to thoroughly review the productive specialization of these economies. This includes their participation in regional and global markets; the link between energy production and consumption patterns and negative externalities caused by pollution, including damage to the health of the population; and weaknesses in rural and urban infrastructure. The degradation of ecosystems and loss of their services will also have to be reversed. The advantages and disadvantages of the different options may vary depending on the country and the international agreements to be established. Due to this changeable and uncertain context, the ECCCA initiative aims to provide a broad analysis that is not necessarily tied to the specific positions of individual countries.

Public policies regarding sustainable and inclusive adaptation could be designed to take into account intra- and inter-sectoral synergies in integrated groupings of policies, with explicit sectoral and territorial goals. The results of the ECCCA initiative suggest that it would be best to explore key policy options by grouping them as follows:

- Inclusion and adaptation of human populations through policies aimed at reducing poverty and inequality, with a focus on food security, comprehensive management of water resources and reduction of extreme event impacts through land management and citizen participation.

- Transition to sustainable, low-carbon economies that are efficient in their use of natural resources, by introducing structural and technological changes related to energy security and efficiency, comprehensive water management, recycling and the reduction of deforestation and pollution.

- Protection and restoration of natural ecosystems and rural landscapes, including forests, in order to improve their adaptation and ensure the long-term provision of environmental services to humans; this is a key component of adaptation and the transition to more sustainable economies, and should address both economic incentives and non-economic, cultural and intergenerational valuations.

- Far-sighted and proactive fiscal and finance policies as a transversal component that establishes climate change resilient criteria for public investments and appropriate incentives for risk reduction, adaptation and the transition towards more sustainable economies, while effectively taking advantage of external financing and national resources, and establishing insurance mechanisms.

- Taking advantage of strategic opportunities for Central American integration, such as management of water resources, food and energy security, trade conditions and international negotiations.

Central American societies need to become bold managers of their water resources and ensure their sustainable and efficient use for direct human consumption, as well as for production. In many ways, the key indicator of adaptation is related to a more efficient use of water resources and its judicious distribution among the many demands; this is of particular importance for the protection of forests and ecosystems. The conservation of forests and restoration of rural landscapes are essential for the management of river basins, for reducing erosion, landslides and floods, and for the production of hydroelectric power. Extensive efforts are required to make more efficient use of water, reduce its contamination and recycle it in the domestic, agriculture, industry and services sectors. A greater challenge is that of creating an effective transnational institutional framework for the sector and its management, given that transnational river basins cover 40% of the territory of Central America.

Protecting food security in the face of climate change, especially access to basic grains, and making the transition to more sustainable and inclusive agriculture is a major challenge that cannot be put off if poor rural and urban citizens are to be protected. With a few notable exceptions, most countries have experienced decapitalization of the rural economy and the dismantling programmes for land titling, outreach, post-harvest loss reduction, market access and capacity building. Much more attention needs to be paid to the protection and promotion of native varieties of crops as well as local, indigenous and national technological know-how, which are underappreciated sources of information on resilience and adaptation to climate change.

The response to climate change in the agricultural sector will need to be closely coordinated with policies aiming to reduce deforestation, protect biodiversity and manage water resources. It will also require recognizing and considering the potential to widely apply successful techniques that have strengthened the welfare of rural and indigenous populations by establishing more sustainable production processes, such as agro-forestry and other activities that combine farming with the protection of natural ecosystems and payment for environmental services. The great agrobiodiversity of the region is currently unprotected, as are the small farmers and indigenous peoples that have developed it over many generations. Efforts to increase access of dispersed rural populations to renewable energy sources, such as solar, wind and small-scale hydroelectric dams, are also very important. In general, rural areas, with their natural and productive resources, will be fundamental to a successful response to climate change.

Technological change is an essential component of adaptation to climate change and the transition to low-carbon economies, both in terms of accessing modern technology and recovering traditional and local knowledge and technology, especially that of indigenous peoples and rural communities. The region is very dependent on highly polluting, imported fossil fuels. The transition to an energy matrix based on local, renewable sources would improve energy security, save foreign currency reserves and reduce the adverse effects of fossil fuels. Appropriate waste management would generate multiple benefits such as reduced pollution, increased raw material for production, power generation through methane capture at landfills and better drainage of water during extreme hydro-meteorological events. A well-designed expansion of hydroelectric power generation that

focuses on sustainability and inclusion could provide people living in poverty with greater access to electricity and contribute to the social and sustainable productive development of populations living in the areas surrounding the power plants.

The energy sector in Central America has designed the Sustainable Energy Strategy 2020 (ECLAC and SICA, 2007)[30], which proposes expanding regional renewable energy sources, including hydroelectric, wind, geothermal, and imported natural gas sources. This is the first regional sectoral strategy that estimates GHG emissions. It was adopted by the Central American presidents and Ministers of Energy, and proposes the following goals:

- Provide access to electricity to at least 90% of the population of each country;
- Reduce the consumption of wood fuel used for cooking by 10%, by introducing more efficient stoves in one million rural households;
- Reduce electricity use by 12% in residences, businesses, industry and public lighting by implementing efficient lighting systems;
- Reduce residential electricity use by 35% by replacing obsolete refrigerators with more efficient ones in 2.7 million households;
- Reduce electricity use in the industrial sector by 10% by using more efficient motors;
- Bring the level of electricity loss in the transmission and distribution systems of Central American countries down to 12%;
- Increase renewable electricity production by 11% as a share of regional energy sources, favouring the construction of hydroelectric plants;
- Replace 15% of petroleum product consumption with biofuels in public and private transport, and
- Reduce GHG emissions by 20% relative to the 2020 baseline scenario, maximizing the use of Certified Emissions Reductions (ECLAC and SICA, 2007).

With greater access to technology and funding, Central America will be able to implement this strategy. The sector has shown its capacity for coordinated, long-term management in developing the network for the Electrical Interconnection System for Central America (SIEPAC). Currently, the sector is working on harmonizing fuel standards within the Customs Union and on the Action Matrix for the Development and Integration of the Energy Sector in Central America.

Human adaptation to climate change is clearly linked to the adaptation of the ecosystems on which humans depend. Meeting this challenge will require further valuation of environmental services, taking into account non-market measures to create appropriate incentives and regulatory frameworks. It is necessary to apply the precautionary principle and establish minimum standards, considering the irreversibility of biological loss, the risk and the uncertainty. Reducing deforestation and degradation, and restoring rural landscapes will generate benefits in many aspects of the development agenda per se, even without considering climate change. It is advisable to broaden and strengthen the system of Protected Natural Areas (of which there are currently more than 550 in the region) and biological corridors, to cover bio-geographical areas on a larger scale and broaden the definitions of protected areas and climate ”refuges”. These efforts can be complemented with programs relating to agriculture, sustainable use of forests and the protection of local crop varieties

and endemic wildlife that are resistant to anticipated climatic effects. Other measures to facilitate the adaptation of forests and rural populations include programs that involve communities in the conservation and recovery of the ecosystems with which they coexist. This includes adopting appropriate technologies for sustainable livelihoods; taking advantage of traditional knowledge and diversifying sources of livelihood; improving forest management systems, including the monitoring of deforestation, forest fires, afforestation and reforestation; and establishing and promoting regulations and certifying organic products and ecotourism.

Environmental land-use management is essential in order to achieve sustainable development and to improve the distribution of the population, its activities and infrastructure, in order to reduce the significant damage and loss resulting from extreme events and accumulated climate changes. Natural ecosystems can reduce the vulnerability of a population to extreme weather events and can serve as complements or substitutes for investment in "grey" infrastructure, which can have higher costs. For example, forests and coastal mangroves provide protection against storms, floods, hurricanes and tsunamis.

It is advisable to broaden and operationalise fiscal and financial policies that provide incentives to transition to higher energy and water efficiency, sustainable forest management and the recognition of the economic value of environmental services, including carbon sinks and water cycle regulation. The region has developed programmes such as the National Forest Financing Fund (FONAFIFO) of Costa Rica, the Protected Areas Conservation Trust of Belize, the Certified Forestry Incentives Programme of Panama, the Forestry Incentives Programme (PINFOR) of Guatemala, and the Incentives Programme for Small-Scale Owners of Land Suitable for Forestry or Agroforestry (PINEP), also of Guatemala. It would be worth examining the benefits of the following: voluntary plans for the net reduction of deforestation at the national and regional levels, with financing from national and international programmes and trusts aimed at adaptation; a broader future version of the Clean Development Mechanism (CDM); other national or international markets for carbon credits and/or payments for environmental services; and national and regional goals for ecological conservation and sustainable use of terrestrial ecosystems. It would be beneficial to tie these conservation goals to measures aimed at improving the wellbeing of the populations, especially for those that coexist with these ecosystems. Some examples of the latter measures are the use of efficient wood stoves, provision of access to electricity and payment for environmental services. It is becoming increasingly necessary to create social awareness regarding the function of ecosystems and the wellbeing associated with them.

There is an urgent need for a sustainable fiscal policy that accounts for the current impacts of extreme events and the growing effects of climate change, and that creates a framework of incentives for the proposed transitions. These climate phenomena are affecting public finances in various ways, such as through the increase in the number of emergencies, and the instability of agricultural production and hydro-electric power generation. They could also give rise to greater demand for the expansion and modification of social services, and the relocation of populations and economic activities. The affected populations would demand compensation for their losses, the cost of which would fall on the State given the low level of insurance coverage in the region. This partial list of pressures on public finances caused by climate change suggests that its economic impact should be seen as a serious contingent liability, which in the long run will become far less "contingent".

Given that the market cannot solve these problems, collective action led by the State (i.e. the combination of public institutions and structures for decision-making and action) is required. Proactive measures must be implemented in order to reduce the negative effects, so that future impacts can be lessened. Financial and insurance mechanisms as well as fiscal-stimulus programmes must be created in order to lessen the impact in general and align fiscal incentives with the transition towards an economy that causes less damage to the environment.

Despite the immediate challenges of the current economic crisis, the Central American Ministries of Finance have begun to pay attention to climate change. The region has experience in swapping debt for climate change programme financing, with budget line "labelling" systems in order to identify investment in adaptation, and is now creating proposals for national funds for climate change, domestic carbon markets, climate change requirements in sectoral plans as part of public budget planning, disaster contingency funds and investment in infrastructure adaptation.

Proactively addressing the challenge of extreme events and climatic variability and change is of utmost importance. If it is not addressed, the current generation will suffer greater losses and damages due to extreme events, and future generations will bear a very high cost of adapting to climate change. This study shows the multiple effects of climate variability and the potential impacts of climate change on various sectors; it points out that the costs of inaction in the face of extreme events and the cost of the impacts of climate change at present day values are too high for immediate, ambitious measures not to be taken. Since climate change involves a market failure, it cannot be treated as the exclusive responsibility of environmental institutions. Rather, it should be seen as a central and transversal economic problem that has serious fiscal implications. Climate change presents a series of multisectoral challenges that need to be tackled jointly by diverse stakeholders, including the public and private sectors, citizens and civil society organizations, academia, integration institutions and the international community.

INTRODUCTION

Although it is estimated that Central America will continue to emit minimal levels of greenhouse gases (GHG), the region is already one of the most exposed in the world when it comes to their effects. Its historical socioeconomic vulnerabilities are exacerbated by its geoclimatic location on a narrow isthmus between two continents and the Pacific and Atlantic oceans. The region is repeatedly affected by droughts, hurricanes and the El Niño-Southern Oscillation (ENSO) phenomenon. Climate change is intensifying these vulnerabilities and will increasingly impact economic development in the region, since climate-dependent factors are fundamental to productive activities such as agriculture. In financial terms, climate change is a contingent public liability that will increasingly affect public finances, which are already facing greater demands due to the impact of a growing number of extreme events.

The region is home to valuable assets that need to be preserved and valued for their contribution to the development of current and future generations. The ecosystems and abundant biodiversity of the region provide multiple services. These ecosystems are deteriorating due to unsustainable development patterns and they will be further depleted by climate change. The population of the region is relatively young and boasts great diversity in terms of culture, ethnicity and lifestyles, and is a valuable asset that requires greater recognition and investment.

At their summit in May 2008, the Presidents of the Central American Integration System (SICA) agreed upon a set of mandates regarding the response to climate change for their national and regional institutions. Since then, concerns about the impacts of this phenomenon have remained on the regional agenda, and the Presidents have ratified and broadened their original mandates in their June 2010, November 2011 and June 2012 Summits. In this framework, the Ministers of Environment and Treasury/Finance, their regional agencies, the Central American Commission on Environment and Development (CCAD) and the Council of Ministers of Treasury/Finance of Central America, Panama and the Dominican Republic (COSEFIN), the Secretariat for Central American Economic Integration (SIECA) and the Economic Commission for Latin America and the Caribbean (ECLAC) have undertaken an initiative titled, "The Economics of Climate Change in Central America". This initiative seeks to establish evidence of the region's vulnerability to climate change, estimate the impacts and potential costs for different sectors, alert decision makers and key stakeholders to the urgency of addressing this challenge and promote dialogue on policy options and national and regional actions. The initiative has received funding from the Department for International Development of the British Government (UKAID) and the Danish International Development Agency (DANIDA), and is managed jointly with the Ministries of Environment and Treasury/Finance.

This analysis examines the potential impact of climate change in Central America in different development and emissions scenarios relative to a macroeconomic scenario without climate change.

Potential impacts are analyzed using a "bottom up" approach by sector or key area, such as agriculture, water resources, extreme events and ecosystems. Impacts are estimated in physical terms, such as agricultural yields and water availability, and as a function of current GDP. Challenges and options for adaptation and the development of low-carbon economies are explored by sector. Future scenarios estimate changes for the end of the century, with intermediate cut-offs at 2020, 2030, 2050 and 2070. Estimates were made for mitigation options for 2030, with intermediate cut-offs at 2010 and 2020 due to higher uncertainty regarding technological changes over longer periods. Since long-term scenarios involve several layers of analysis with uncertainties and methodological difficulties, results should be interpreted as trends and relative magnitudes, not as predictions or exact magnitudes.

The two GHG emission scenarios used here are from the Intergovernmental Panel on Climate Change (IPCC). The more pessimistic scenario (A2) predicts a continuous increase in global GHG emissions, resulting in a significant increase in temperature and substantial decrease in rainfall in most of Central America. The basic assumptions of this scenario are a growing world population in which regional human fertility patterns gradually converge, economic development focused on the regional level, and slow and fragmented per-capita economic growth and technological change. This scenario warns of great risks for the region if the international community fails to curtail the current trajectory of global GHG emissions.

The less pessimistic scenario (B2) predicts a less substantial decrease in rainfall throughout most of the region and a less significant temperature increase, assuming a lower GHG emissions growth trajectory than A2. The basic assumptions of this scenario are a development model aimed at local economic and social solutions, a lower rate of world population growth than that of A2 and moderate economic growth. This scenario would probably require international agreements and actions to substantially reduce global GHG emissions growth in the short term.

Results to date suggest that the impacts of climate change on Central America in the more pessimistic scenario (A2) would be significant and grow over time. This would confirm the asymmetry inherent in the fact that countries that have least contributed to the problem face greater damages and are less resilient. The costs of the impacts in this scenario of global inaction, especially on the part of the major GHG-emitting countries, would be higher than those of a scenario with a lower emissions growth trajectory (B2) and agreements that allow the most vulnerable countries, such as the Central American countries, to implement adaptation and mitigation measures within a framework of sustainable and inclusive development. It is clear that climate change is the greatest market failure to date, as the market has not internalized the value of the climate as a global public good or properly accounted for its social and environmental services. In addition to economic valuations of these externalities, ethical decisions need to be made regarding the value assigned to the needs of future generations and the ecosystems that provide many environmental services. The latter will be lost long before the market sends the necessary signals to motivate changes in their management. Since it is a market failure, climate change cannot be treated as the sole responsibility of environmental institutions. It should be viewed as a central and transversal social and economic problem with serious financial implications.

Adaptation requires renewed efforts to reduce poverty, inequality and socioeconomic and environmental vulnerability while increasing the capacity of societies, specific populations and related ecosystems to adapt. Central American societies need to avoid ad hoc strategies that might

resolve emergencies but increase risks. The idea that climate change cannot be addressed because of budgetary constraints that have been worsened by the current global recession or because of existing urgent social and economic issues would be counterproductive in the medium term. It is more advisable to promote **inclusive and sustainable adaptation strategies** that combine actions to reduce poverty and vulnerability to climate extremes with actions to adapt to climate change and transition to more sustainable, low-carbon economies. This requires a strategic vision to maximize intersectoral co-benefits and minimize the intersectoral costs of adaptation, mitigation and national development agendas, which have traditionally been addressed separately. In this manner, the current global economic recession and risks of climate change can be seen as an opportunity to thoroughly review the productive specialization of Central American economies. This includes their participation in international markets, the negative impacts of their energy, land and water use patterns, weaknesses of rural and urban infrastructure, and the degradation of ecosystems. Ultimately, this implies special attention to inclusion and sustainability in its many forms.

The 2010 Summary and the 2011 Technical Report were published with the goal of discussing, disseminating and using the results of this initiative in the formulation of national and regional strategies and have been presented at national and regional events with civil servants, representatives of non-governmental organizations, trade unions, the private sector, universities and research centers. The results have served as inputs in the training of national committees on climate change and negotiating teams, as well as in the preparation of the Regional Climate Change Strategy, several international financing projects and various national policies. The results have been presented in coordination with the Ministries of Environment at the last three Conferences of the Parties of the United Nations Framework Convention on Climate Change

Given this progress, the partners of the initiative agreed to devote more attention to sectoral, spatial and temporal analysis. Analysis has been carried out of climate variability based on data from meteorological stations, climate change scenarios at the subnational scale and inter-annual patterns, potential changes in indicators of aridity, and potential impacts on hydroelectric power generation in Guatemala and El Salvador. The Ministries of Health and the Council of Ministers of Health of Central America and the Dominican Republic (COMISCA) are collaborating with ECLAC, the Pan American Health Organization (PAHO) and several expert institutions to advance in analysis of the potential impacts of climate change on climate-sensitive diseases such as malaria, dengue and respiratory illnesses. The initiative is also working with the Ministries of Treasury/Finance to develop a work programme that includes a series of technical courses, and with the Ministries of Energy to further integrate the response to climate change into the Central American Sustainable Energy Strategy 2020. The initiative is also preparing a working agenda with the Ministries of Agriculture and the Central American Agricultural Council (CAC) on scenarios of basic grain yields on a subnational scale, options for integrated risk management, insurance and food security challenges. This Summary and the 2012 Technical Series present some of these recent advancements and seek to contribute to the technical discussion and training needed in the region.

I. POTENTIAL IMPACTS ON INTRA-ANNUAL AND SPATIAL CLIMATE PATTERNS

The goal of this study on the potential impacts of climate change on intra-annual and spatial climate patterns is to present a temporal and spatial disaggregated analysis of possible temperature and precipitation changes in Central America (ECLAC, COSEFIN, CCAD/SICA, UKAID, DANIDA, 2012a). The study aims to contribute to the design of adaptation measures for specific geographical areas. The evolution of both variables and their intra-annual patterns (by month) are analyzed by country, department and a proposed geoclimatic division that takes into account the diversity of climate, especially with regard to rainfall. Estimates are made for several cut-off years up to the end of the century in two climate-change scenarios: A2, the more pessimistic scenario, and B2, the less pessimistic scenario. This study complements the previous analysis by country and annual patterns, available in the first chapter of ECCCA's 2011 Technical Report (ECLAC, CCAD/SICA, UKAID, DANIDA, 2011a).

The study uses average monthly temperature (°C) and monthly accumulated precipitation (mm) by country and department, district or province, depending on the term used in each country. The term "department" is used as a generic term for these administrative divisions when speaking of the region as a whole. The Kuna Yala and Ngöbe-Bugle regions of Panama have their own estimates. Due to geographical location and availability of data, it is recommended that figures from the province of Panama be used for the region of Madugandí and figures from Darién be used for the regions of Emberá-Wounan and Wargandí. With the guidance of the delegates of the Ministries of Environment and local meteorologists, three large geoclimatic regions were identified: Pacific, Atlantic and Central. Departments with extensive coastlines are included either in the Pacific or Atlantic regions, while departments with little or no coastline are included in the Central region. A fourth region, the Western Highlands, was added for Guatemala.

The analysis by country used monthly averages from the CRU TS3.0 database for the period 1980-2000. The analysis by department and geoclimatic region used monthly averages from the WorldClim database for the period 1950-2000. In estimating the scenarios by country for the end of the century, averages from the HADCM3, GFDL R30 and ECHAM4 models were used for B2 and averages from the HADGEM1, GFDLCM2.0 and ECHAM5 models were used for A2. The analysis by department and geoclimatic region used averages from the ECHAM4 and HADCM3 models for B2 and averages from the ECHAM4 and HADGEM for A2. In order to clearly identify trends, ten-year averages were calculated for each cut-off year: 2020 (2016-2025 average), 2030 (2026-2035 average), 2050 (2046-2055 average), 2070 (2066-2075 average), and 2100 (2091-2100 average). Since the scenarios are long-term and have several "layers" of analysis with uncertainties and methodological difficulties, results should be interpreted as trends and relative magnitudes, not as predictions or exact magnitudes.

In the previous study on the potential impacts of climate change on temperature at the country level, available in the 2011 Technical Report, it was estimated that temperatures would increase by between 0.50°C and 0.57°C (for B2), and between 0.63°C and 0.80°C (for A2) by 2020, showing that impacts would differ by scenario even in the short term. Differences increase over time, reaching ranges of between 2.20°C and 2.67°C (for B2) and between 3.60°C and 4.73°C (for A2) by 2100.

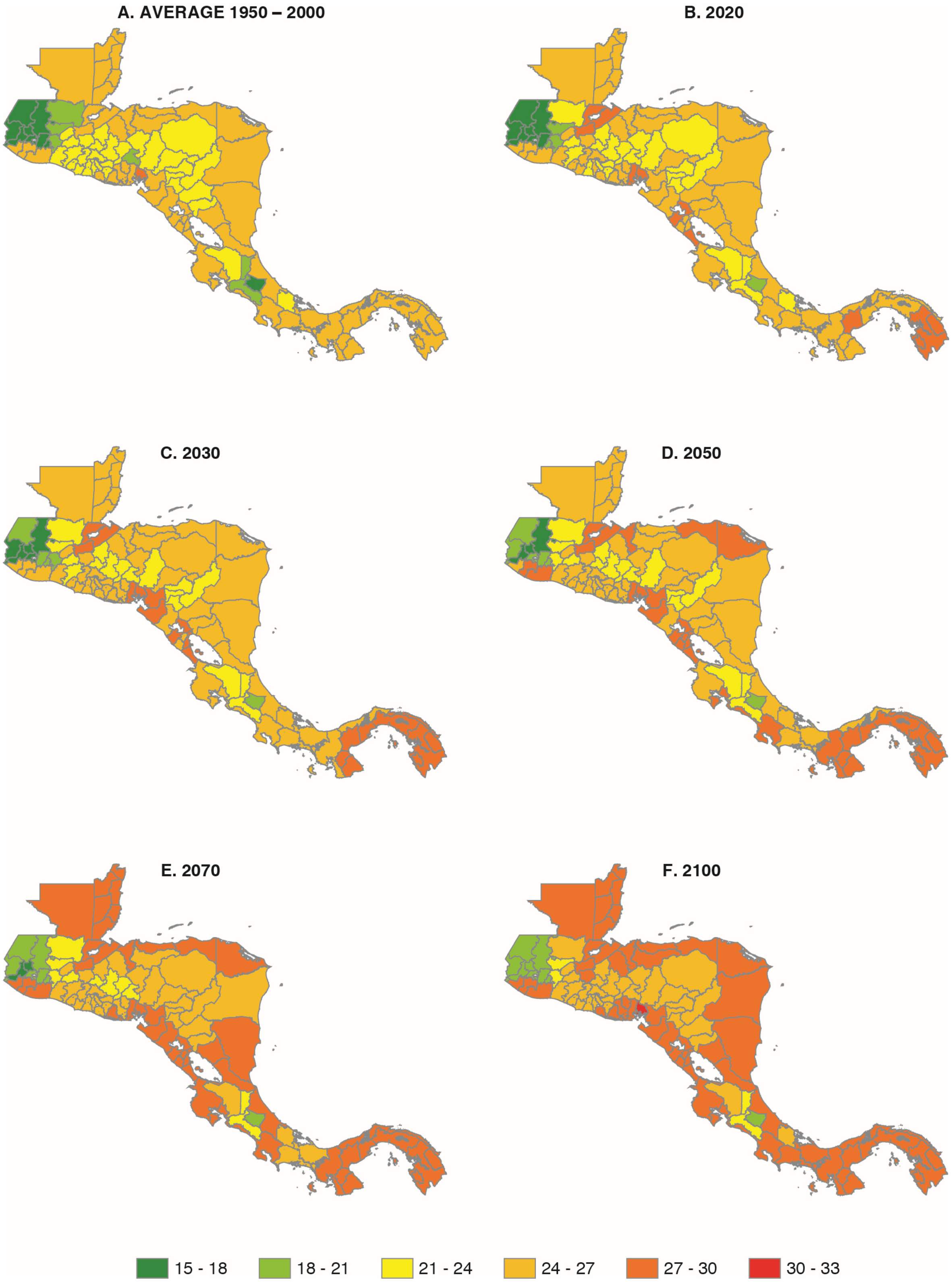
Under scenario B2, the average annual temperature would gradually increase (see Map 1). By 2020, 52 departments would experience temperatures between 24°C and 27°C, compared to 49 departments in the same range during the historical reference period. By 2050, the number of departments in this range would decrease to 45, but by the same time, 25 departments would experience temperatures between 27°C and 30°C. By 2100, the Central region would experience the greatest temperature increase, of 3.1°C, while the Atlantic region would experience the lowest, 2.5°C. The department of Valle, Honduras, would experience temperatures between 30°C and 33°C, and would be the only department in this range. The Central region would experience temperatures between 24°C and 27°C by 2100, while temperatures in Guatemala's Western Highlands and Costa Rica's Central Valley could reach between 18°C and 21°C.

Under scenario A2, temperature increases would be greater (see Map 2). By 2020, 56 departments would experience temperatures between 24°C and 27°C, and eight departments would experience temperatures between 27°C and 30°C. By 2070, temperatures in the department of Valle, Honduras, would reach between 30°C and 33°C, and by the end of the century, eleven other departments would reach the same range. The rest of the Pacific and Atlantic regions would see temperatures between 27°C and 30°C, with the exception of some departments in El Salvador, Guatemala and Panama, which would experience temperatures between 24°C and 27°C. Temperatures in the Atlantic region would increase by 3.7°C with respect to the historical period, but the Western Highlands of Guatemala would experience the greatest increase of 4.8°C. At the country level, Guatemala and Costa Rica would experience the largest range of temperatures, followed by Nicaragua and Honduras. Such variation could allow for more options for adaptation in agriculture.

Figures 1 and 2 show the average monthly temperature by country under scenarios B2 and A2 at the end of the century. The most notable change is the progressive increase in temperature every month, with differences depending on country and month. A2 estimates are the most extreme; however, significant changes in intra-annual patterns are not detected. That being said, Belize, El Salvador, Guatemala and Honduras would experience greater relative temperature increases between April and October under scenario A2.

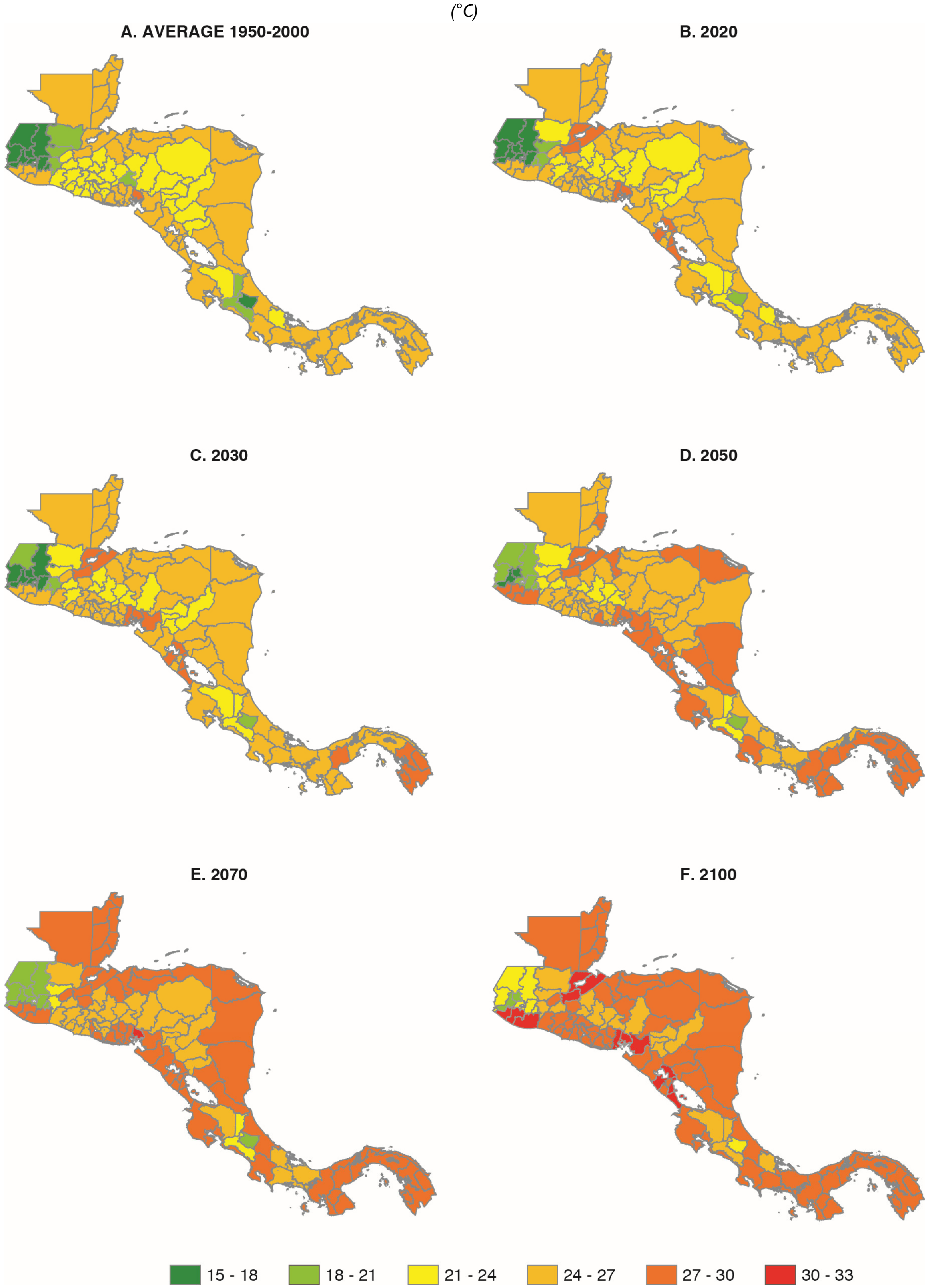
The first analysis of the climate change scenarios carried out by the ECCCA initiative estimated that annual accumulated precipitation by country could experience variations of between -0.7% and 6.2% (for B2) and -3.5% and 1.8% (for A2) towards 2020 with respect to the period 1980-2000. However, it is estimated that towards 2050, figures will decrease in both scenarios and worsen during the rest of the century, especially under scenario A2. It is estimated that by 2100, there will be changes of between -2.9% and -17.4% (for B2) and -17.5% and -34.9% (for A2). The smallest decreases would occur in Panama and Costa Rica. It should be noted that using general climate circulation models presents more difficulties when modelling precipitation than when modelling temperatures; the models used produce variable precipitation results. Nevertheless, it is possible to detect general trends. All of the models foresee greater decreases or smaller increases in A2 than in B2.

MAP 1
CENTRAL AMERICA: ANNUAL AVERAGE MONTHLY TEMPERATURE BY DEPARTMENT, 1950-2000 AVERAGE AND SCENARIO B2 UP TO 2100.
(°C)



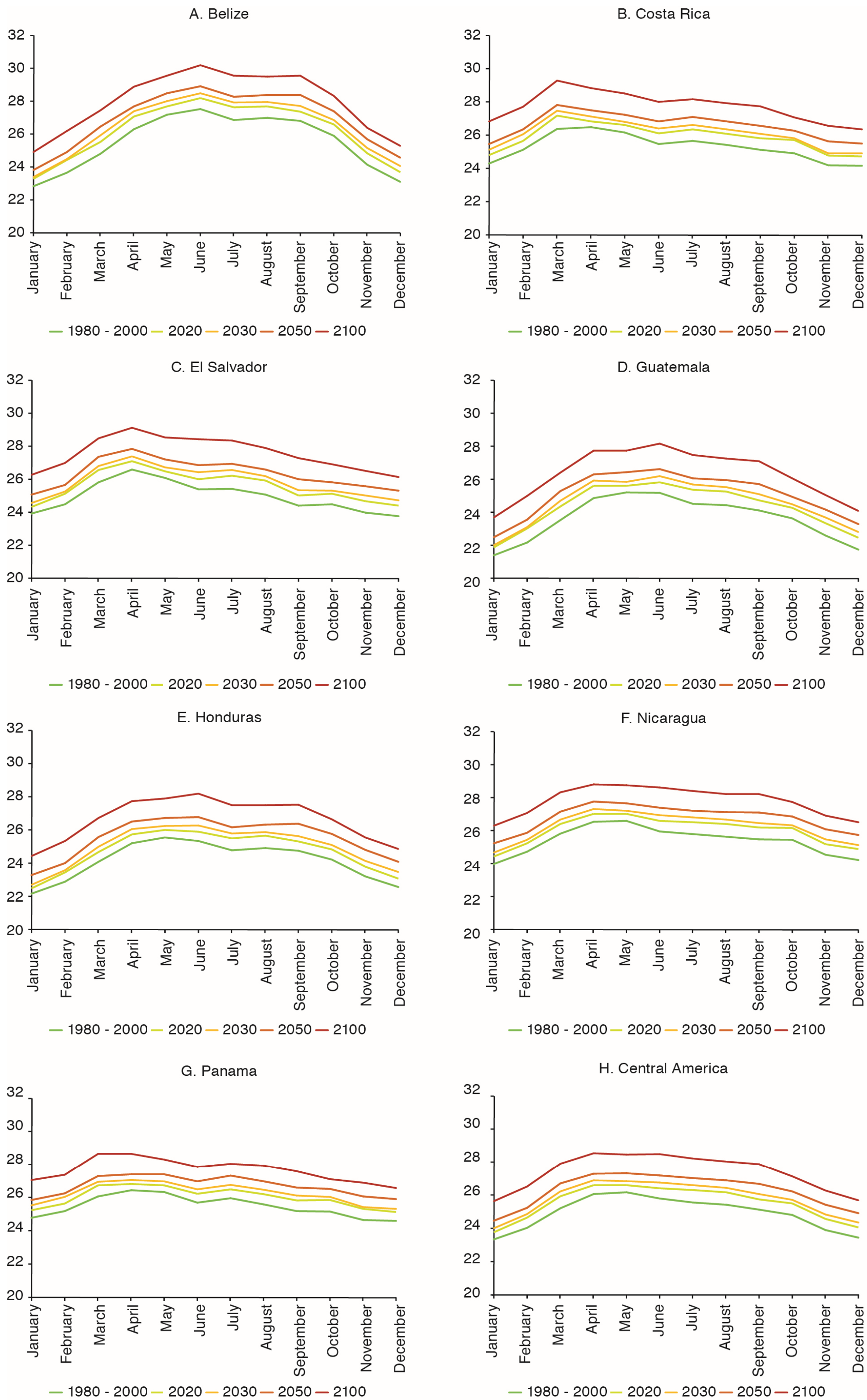
Source: Prepared by the authors.

MAP 2
CENTRAL AMERICA: ANNUAL AVERAGE MONTHLY TEMPERATURE BY DEPARTMENT, 1950-2000 AVERAGE AND SCENARIO A2 UP TO 2100.
(°C)



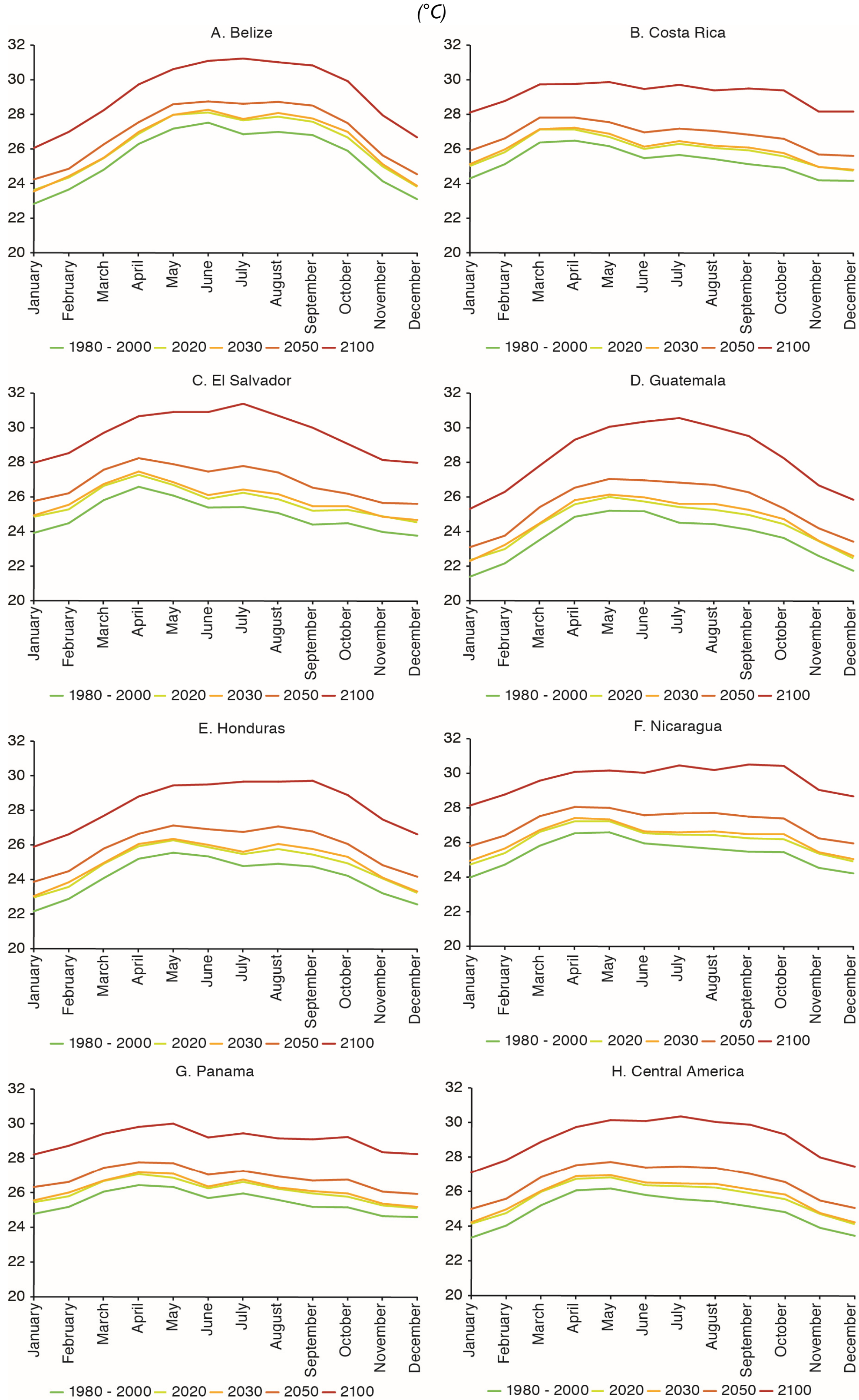
Source: Prepared by the authors.

FIGURE 1
CENTRAL AMERICA: AVERAGE MONTHLY TEMPERATURE, 1980–2000 AVERAGE AND SCENARIO B2 UP TO 2100
(°C)



Source: Prepared by the authors.

FIGURE 2
CENTRAL AMERICA: AVERAGE MONTHLY TEMPERATURE, 1980–2000 AVERAGE AND SCENARIO A2 UP TO 2100
(°C)



Source: Prepared by the authors.

During this century, under scenario B2, rainfall would diminish slightly or remain stable in the four geoclimatic regions (see Map 3). The Atlantic region would experience the greatest decrease of 6.1%. Guatemala's Western Highlands would experience an increase of 0.4%. Under scenario A2, there would be fluctuations in precipitation over the next two decades, depending on the region, but a downward trend would set in and continue to grow as the century progresses (see Map 4). By 2020, this would lead to 18 departments having precipitation levels between 65 mm and 110 mm compared to 11 departments during the reference period, while two departments pertaining to the dry corridor would descend to levels between 20 mm and 65 mm—a range without precedent during the reference period. By 2050, 26 departments would find themselves in the 65 mm-110 mm range, and four from the dry corridor would fall to the 20 mm-65mm range. By this time, only six departments would experience the highest rainfall range of 245 mm-290 mm, compared to 11 departments during the reference period. Finally, by 2100, 31 departments would be in the 65 mm-110 mm range, and 11 departments would be in the 20 mm-65 mm range, some of them located in the dry corridor of Guatemala, Honduras and Nicaragua. By this time, no department would experience rainfall levels between 245 mm and 290 mm.

The changes in the intra-annual precipitation pattern under scenario B2 are shown in Figure 3 and those of scenario A2, in Figure 4. During the period 1980-2000, the rainy season in Central America lasted from May to October, reaching its peak in September and October, and presented slightly bimodal behavior in the dog days of July and August. Towards 2020, under scenario B2, rainfall levels would rise between May and July compared to the reference period, reaching their maximum in June. They would then gradually decrease until August and this pattern of lower rainfall levels would last until December, with respect to the reference period. Therefore, the rainy season would be more unimodal heading towards 2050, with the greatest rainfall occurring between May and July. By 2100, the amount of precipitation in the early stages of the rainy season would be lower than in the period 2020-2050, reaching its annual maximum in May. This would be followed by a gradual decrease until August (with a short period of dog days), a slight increase in September, and then a continuous decrease until the end of the year.

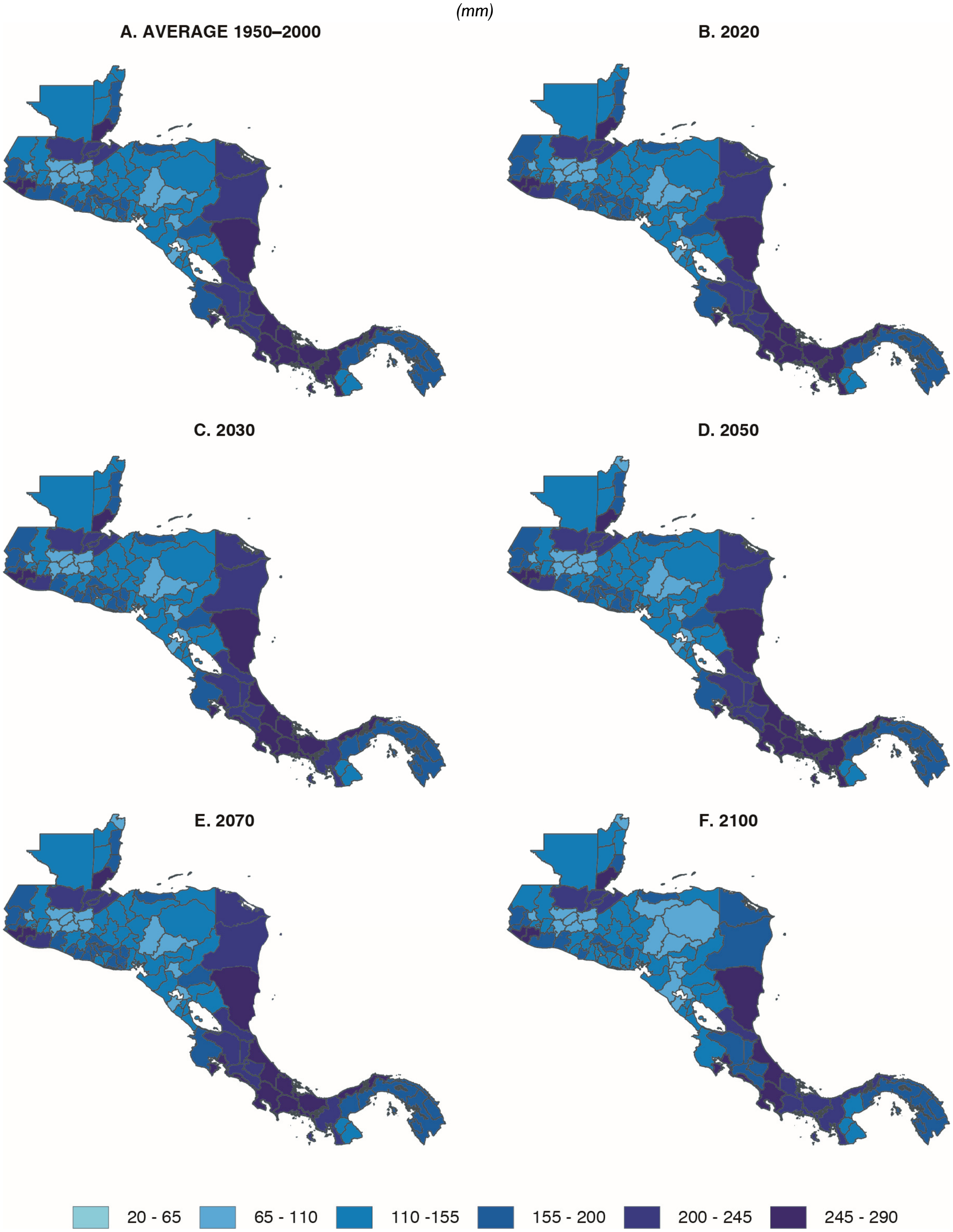
Under scenario A2, the next two decades could bring greater precipitation to Central America in June and July, a marked period of dog days, and a second rainy period from September to October with greater precipitation, accentuating the bimodal pattern. Later, this pattern would end, as precipitation would decrease during the entire season, especially during the first period from May to August, resulting in a unimodal pattern by 2100; precipitation would begin with low levels in May and gradually increase, reaching a maximum in October to then conclude the season in November.

Regarding Central America's intra-annual precipitation patterns, it is estimated that under scenario B2, rainfall would increase at the start of the season (which could possibly begin earlier in the year) during the next two decades. At the same time, and especially during the second half of the century, precipitation following the dog days would decrease, causing some countries to lose their bimodal behavior. Maximum rainfall will shift from after the dog days to before it by the end of the century, except in Nicaragua. By 2100, maximum rainfall in Belize and Costa Rica would shift from October to May; in El Salvador and Guatemala, from September to May; in Honduras, from September to June; in Panama, from October to June; and in Nicaragua, from June to May.

Under A2, it is estimated that over the coming decades, the bimodal pattern could be exacerbated, with increases in the two periods of heavy rainfall, and decreases during the dog days. Later, rainfall in the early stages would gradually decrease, leaving a single annual maximum between October and November. In Belize, the pattern would evolve differently since the dog days have been relatively mild; rainfall would decrease at the start of the season, and even further during the dog days, increasing again after the dog days. Panama could experience an increase in rainfall at the start of the season over the next few decades, and then a decrease to near-historical lows, resulting in a relatively stable pattern from June to November. Therefore, the periods of maximum accumulated rainfall would be different from the historical ones: from September to October in Belize, El Salvador, Guatemala and Honduras; from June to October in Nicaragua, and from October to August in Panama. Costa Rica's period of maximum accumulated rainfall would continue to occur in October.

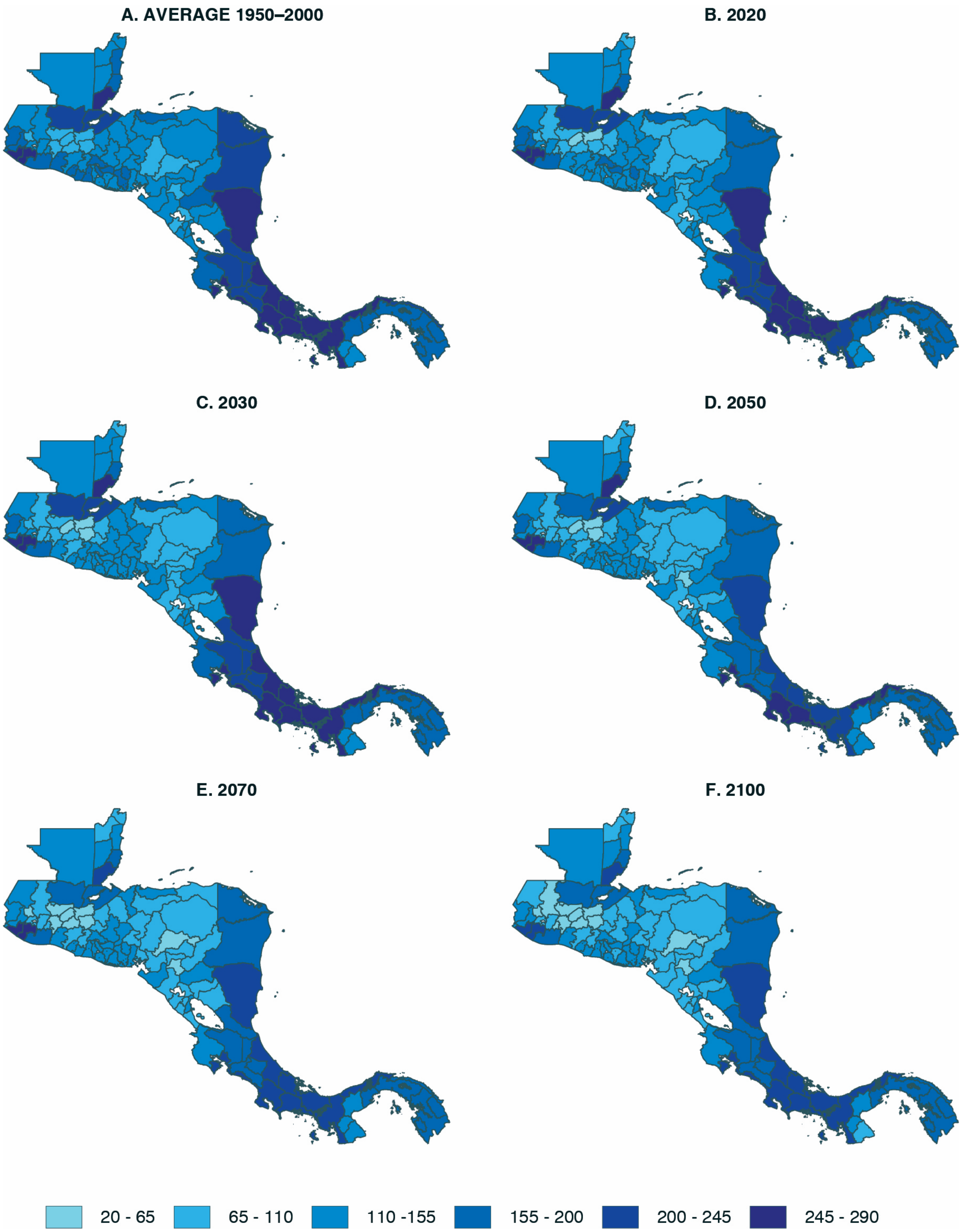
To summarize, this study shows that the climate change scenarios estimate different impacts on temperature and precipitation depending on the country, department and geoclimatic region. The information presented in this report, by cut-off year and intra-annual patterns, is a useful tool to refine the analysis of potential impacts on agriculture, health and energy, and to design adaptation measures for specific zones. This information has been used by two additional studies in this series: one on indicators of aridity, and the other on the potential impacts on hydroelectric power generation. It should be stressed that designing measures to reduce the risks associated with climate change requires analysis based on local, national and regional (Central American) climate data. Several countries have begun initiatives to expand and improve their network of meteorological and hydro-meteorological stations as well as the training of climatology professionals. Said efforts must be prioritized and increased in the future.

MAP 3
CENTRAL AMERICA: ANNUAL AVERAGE MONTHLY PRECIPITATION BY DEPARTMENT, 1950-2000 AVERAGE AND SCENARIO B2 UP TO 2100
(mm)



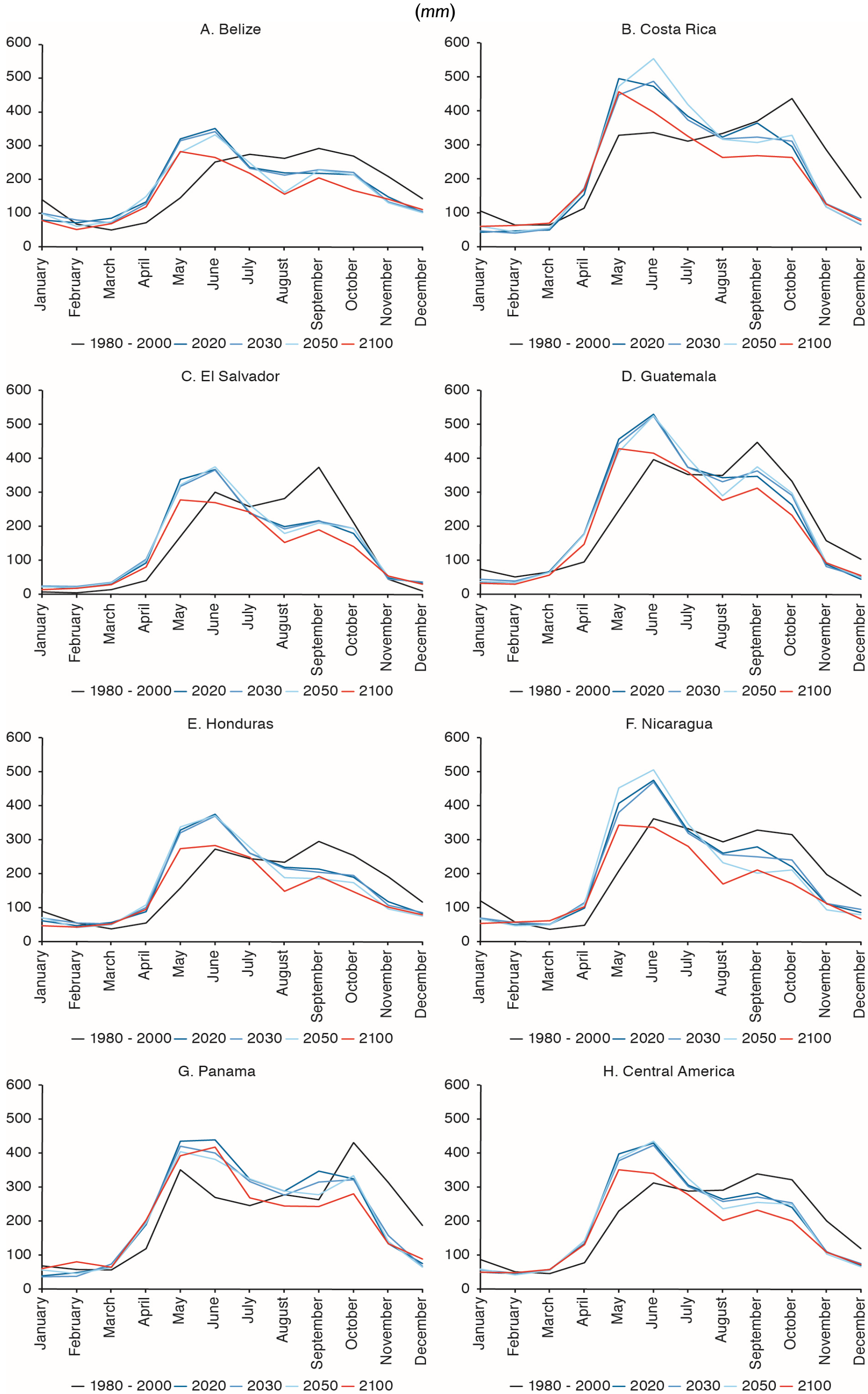
Source: Prepared by the authors.

MAP 4
CENTRAL AMERICA: ANNUAL AVERAGE MONTHLY PRECIPITATION BY DEPARTMENT, 1950-2000 AVERAGE AND SCENARIO A2 UP TO 2100
(*mm*)



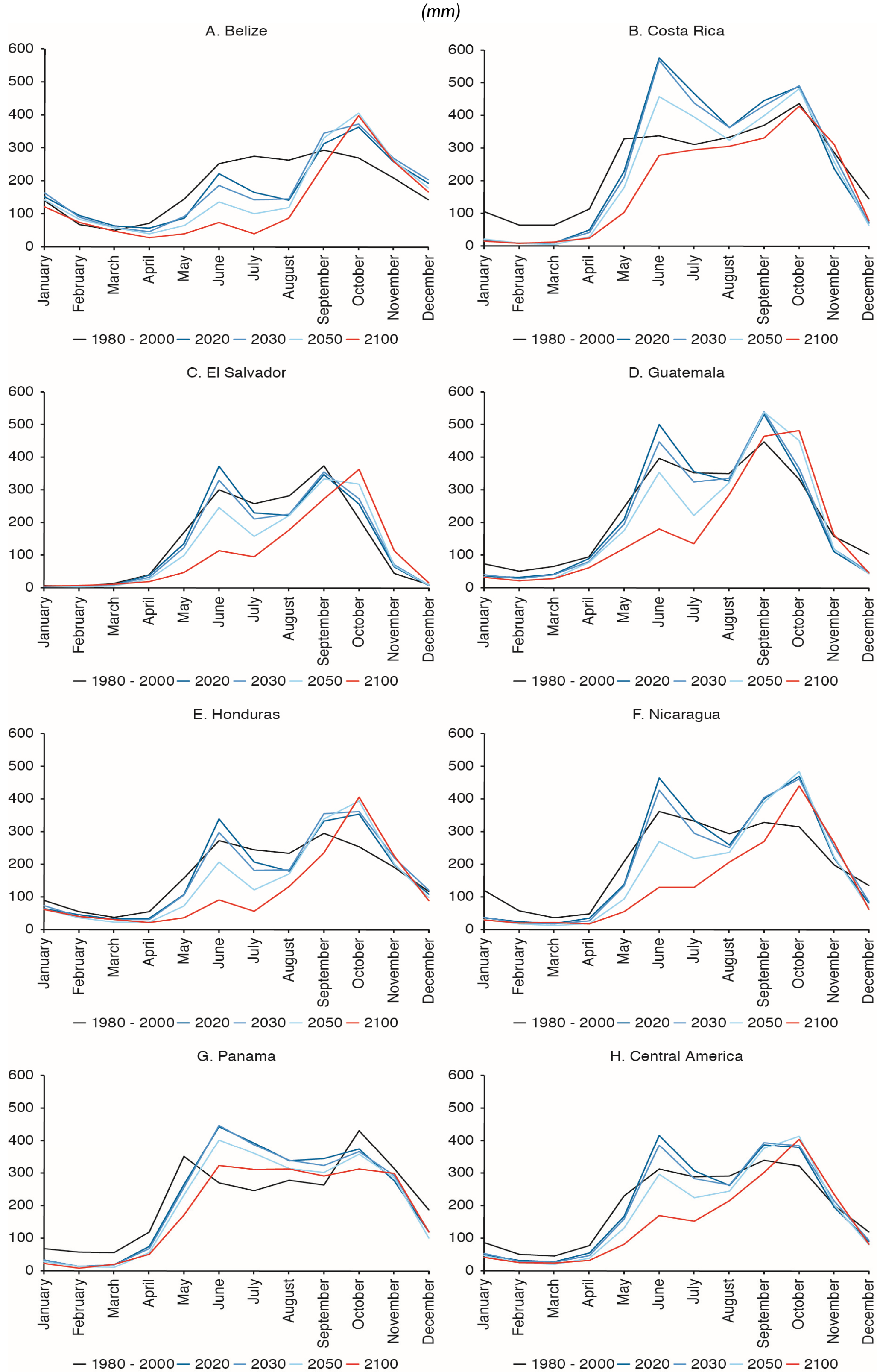
Source: Prepared by the authors.

FIGURE 3
CENTRAL AMERICA: MONTHLY RAINFALL, 1980-2000 AVERAGE, AND SCENARIO B2 UP TO 2100
(mm)



Source: Prepared by the authors.

FIGURE 4
CENTRAL AMERICA: MONTHLY RAINFALL, 1980-2000 AVERAGE AND SCENARIO A2 UP TO 2100
(mm)



Source: Prepared by the authors.

2. EVIDENCE OF CLIMATE VARIABILITY

In its Fourth Assessment Report (2007), the IPCC indicated that the frequency of intense rainfall events has increased over most land masses, consistent with the warming and increase in water vapor that has been observed. The IPCC, in its recently published report on extreme events, concludes that there is medium confidence that anthropogenic influences have contributed to the intensification of extreme precipitation at a global scale and to droughts in some regions, including Central America, due to the decrease in rainfall and/or the increase of evapotranspiration (IPCC, 2007b; IPCC, 2011).

International experts believe that it is easier to analyze the link with temperature extremes than with hydro-meteorological events, which are more complex and present greater uncertainty. In its special report on extreme events, the IPCC states that extreme changes can be related to changes in the average, variance, probability distribution or all of these indicators combined. The IPCC also believes that some climate events, like droughts and landslides, might be caused by the cumulative effect of multiple events that are individually not considered extreme. The Panel states that natural climate variability will continue to be an important factor in the future, adding to the effects of changes associated with anthropogenic activities (IPCC, 2011).

At the international level, a number of extreme hydro-meteorological events have taken place in different parts of the world, such as Russia's heat wave in 2010 and floods in England in 2000, in Pakistan in 2010, and very recently in Thailand. These events have led to more discussion and analysis about the possible influence of climate change on the greater severity of these events.

In October 2011, the tropical depression named 12-E and a related type of low-pressure system affected El Salvador, Costa Rica, Guatemala, Honduras and Nicaragua. Concern about this phenomenon led the presidents of these five countries to hold a special summit, where a team of consultants was brought in to support the countries in their reconstruction efforts with a view to reducing vulnerabilities and adapting to climate change. The intensity and duration of rainfall were considered to be concrete manifestations of the adverse effects of climate change (Comalapa Statement, October 25, 2011)[2] .

Until recently, experts did not consider the possibility of establishing a partial or incremental link between climate change and a specific extreme event; nor had there been much progress in attributing the observed trends of these events to climate change, with the exception of the

[2] In preparation for this summit, the Pro Tempore Presidency of CCAD/SICA requested the collaboration of the ECCCA initiative on the document titled "Analysis of the Effects of Climate Change in Central America" , which was prepared by CCAD and the Coordination Centre for the Prevention of Natural Disasters in Central America (CEPREDENAC). The paper relied on input from the CU team at the Subregional Headquarters of ECLAC in Mexico, RTC delegates, the meteorological services of the five countries, and other civil servants who shared their knowledge and facilitated access to meteorological databases.

relationship between a greater intensity of tropical storms and the increase in sea surface temperatures. However, during the last two or three years, international experts have begun to analyze the changes in extreme event patterns and search for evidence that link these variations to climate change. There have even been a number of important documents published on this subject in the last few months. The literature to date suggests that there is serious concern and demand for information regarding this potential relationship, and that even though there are significant uncertainties, evidence of this relationship is beginning to accumulate and cases of probable partial attribution to climate change are being identified.

One of these recent studies, carried out by Pall and others (2011), uses a framework of probabilistic attribution for the floods that occurred in England and Wales in 2000, contrasting climate data from the events with a model that presupposes a lack of global warming. The authors reported that in nine out of ten cases, results showed that emissions over the last 100 years increased the risk of flooding by 20%, and in two of every three cases, by more than 90%. Hoerling and others (2011) analyzed the trend of decreasing winter precipitation in the Mediterranean region and its possible relationship with natural variability, the North Atlantic Oscillation (NAO) and anthropogenic climate change. The authors found that climate change can explain approximately half of the increase in dryness that occurred between 1902 and 2010, primarily due to the rising temperature of the surface of the Mediterranean Sea.

Rahmstrof and Coumou (2011) used a Monte Carlo model to assess the likelihood that the high temperatures in Moscow in July 2010 were probable given recorded temperatures for July during the last century. They found that without climate change, the probability that this heat wave would not have occurred was 80%. These results and those provided by Tamino (2010) partly contradict a previous study by Dole and other (2011), which concluded that Moscow's heat wave had been caused primarily by natural internal atmospheric variability.

Another environmental group from Canada (Min and others, 2011) compared precipitation time series for North America with six climate model simulations, with and without climate change, and found that the extreme rainfall patterns observed did not align with the expected natural cycle, but were close to the patterns expected with climate change. These reports suggest that the concern over the possible exacerbation of extreme events by climate change is legitimate, particularly in regions such Central America, due to its historical exposure to such events.

The international initiative Attribution of Climate-related Events (ACE) was launched in 2009 with the participation of the Hadley Center, the Department of Energy and Climate Change of the UK, various departments of the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR) and several universities. In October 2011, ACE presented a progress summary at the World Climate Research Programme (WCRP) Conference and proposed options for fractional attribution methodology, i.e. attributing the changes in the risks of extreme events to specific factors, including climate change (Stott and others, 2011).

One line of research on the relationship between climate change and extreme events, such as floods and intense precipitation, is based on the laws of thermodynamics which indicate that an increase in temperature gives rise to greater levels of evaporation, evapotranspiration, atmospheric water vapor and an acceleration or destabilization of the water cycle (Flower, Mitchell and Codner,

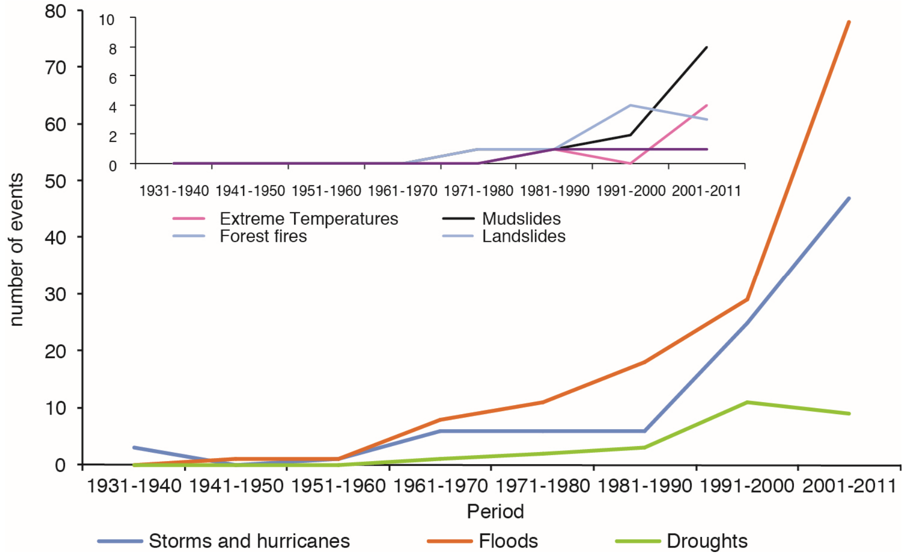
2007; Ekström and others, 2005). Stott, of the Hadley Center, has estimated that for each additional temperature increase of 1°C, average global atmospheric humidity increases by 7%, which leads to precipitation events of greater intensity (Carey, 2011).

Historical climatology shows that Central America has experienced an average temperature increase of approximately 0.5°C over the last 50 years. Under a scenario in which GHG emissions continue their current upward trajectory, the temperature could increase by between 1°C and 2°C by 2050 (ECLAC, CCAD/SICA, DFID, DANIDA, 2011a). Furthermore, a study on the trend of droughts in the Mediterranean region has found that the sea surface temperature could act as a transmission channel for climate change, leading to precipitation and extreme events. The time series indicates that the area of the Pacific associated with ENSO (20 N-20 S and 90 W-120 W) has experienced a temperature increase in this century (http://climexp.knmi.nl/start.cgi?someoneomewhere). With regard to the Caribbean Sea, there is evidence of accelerated warming since the second half of the 1990s (Jury, 2011).

Another line of preliminary analysis involves considering evidence of changes in extreme event trends, such as tropical storms, hurricanes and floods. According to the IPCC Fourth Report, in nine out of the ten years in the period 1995-2005, the number of hurricanes in the North Atlantic surpassed the historical trend recorded from 1981 to 2000 (IPCC, 2007b). Droughts have also tended to be more intense since 1970, mainly in the tropics and subtropics. Between 1931 and 2011, the Central American countries experienced 291 extreme events associated with hydro-meteorological phenomena (see Figure 5). Honduras experienced the greatest number, with 62, and Belize the least, with 19. The most recurrent events are floods, storms, landslides and mudslides, which account for 86% of total events, and droughts, which account for 9%. During the last three decades, the number of natural disasters in the region grew by 7% per year with respect to the 1970s.

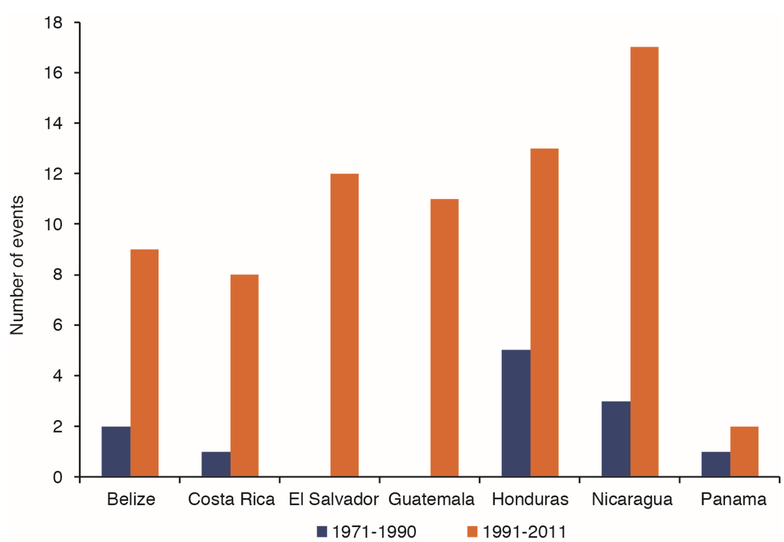
It has been observed that there has been a sustained increase in the number of events over time, especially since the 1960s, with a significant increase from 1991 to 2010. In the last two decades, the number of floods has more than doubled in all of the Central American countries with respect to the period 1971-1990. Costa Rica, Honduras and Panama have experienced the most floods, while El Salvador, Guatemala and Nicaragua maintain an intermediate frequency. With regards to recorded storms and hurricanes, Nicaragua has experienced the most in the second period, with 17 events (see Figure 6). The other countries experience an average of 8-9 events, i.e. one storm or one hurricane every three years. El Salvador and Guatemala stand out, as they did not experience any extreme events of this type during the first period, but experienced the greatest increase in the period 1991-2011. Landslides and extreme temperatures have started to show a growing trajectory in recent years, as have droughts and forest fires since the 1990s. It is important to note that these figures don't include small-scale events that often have severe impacts on specific communities and cumulative effects in the medium and long-term.

FIGURE 5
CENTRAL AMERICA: EVOLUTION OF RECORDED EXTREME EVENTS OVER TIME, 1931-2011
(By number and type)



Source: Prepared by the authors, using EM-DAT (CRED, 2012).

FIGURE 6
CENTRAL AMERICA: NUMBER OF TROPICAL STORMS AND HURRICANES RECORDED IN TWO PERIODS, 1971-1990 AND 1991-2011
(By number)

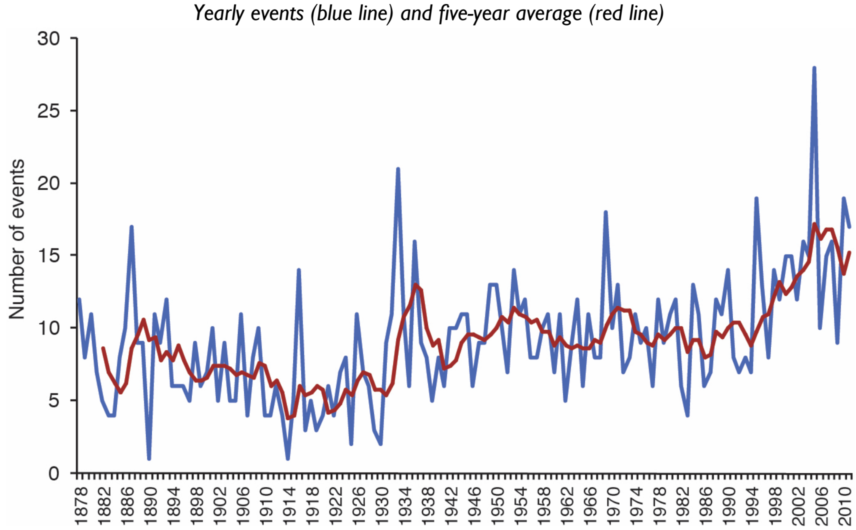


Source: Prepared by the authors using EM-DAT (CRED, 2012); does not necessarily show all significant events.

According to the IPCC Fourth Report, the annual number of hurricanes in the North Atlantic between 1995 and 2005 increased in nine out of ten years, surpassing the historical trend recorded between 1981 and 2000 (IPCC, 2007b). Droughts have been more intense as well, mainly since 1970, in the tropics and subtropics. Figure 7 illustrates the time series of hurricanes and storms (HURDAT) for the Atlantic Ocean recorded by the NOAA between 1878 and 2006. The time series shows great volatility, with an increase in storms and hurricanes, especially over the last two decades.

Nevertheless, it is not yet possible to determine that this trend is outside the historical cycle (Hegerl and others, 2007; Vecchi and Knutson, 2008). Although the databases for Central America are incomplete, the records that are available suggest that this trend has also been experienced in the region.

FIGURE 7
NORTH ATLANTIC OCEAN: NUMBER OF HURRICANES, AND TROPICAL AND SUBTROPICAL STORMS, 1878-2011
Yearly events (blue line) and five-year average (red line)



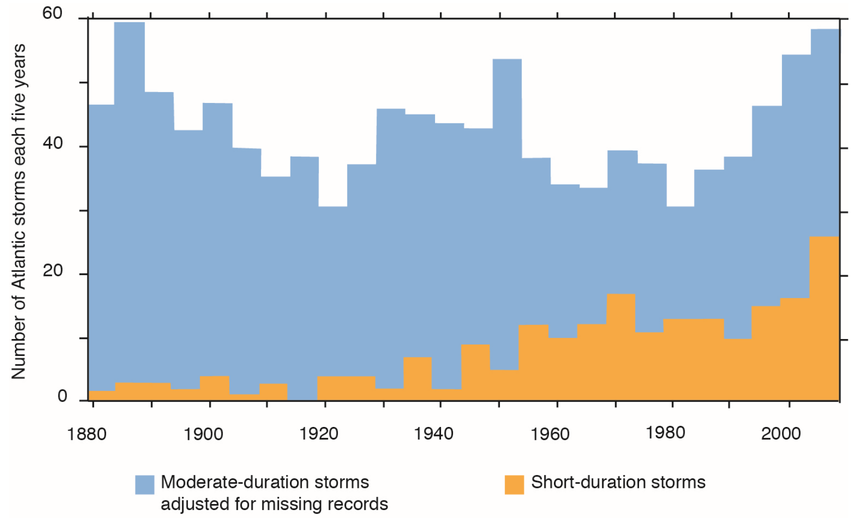
Source: Prepared by the authors using HURDAT (NOAA, 2011).

By disaggregating events of short and moderate duration, Figure 8 shows that the frequency of tropical storms of short duration (less than two days) in the Atlantic Ocean has gradually increased, especially since 1960. In light of the increased frequency of intense rains seen in some areas of the region, it would be advisable to analyze the possible relationship between this trend and climate change.

Storms of moderate duration exhibit a possible multidecadal fluctuation, with a trajectory that has changed since 1980. The relationship between the frequency of these events and climate change could be identified once it becomes clear whether or not the frequency pattern abandons its historic oscillation in the coming decades.

With regard to the spatial distribution of tropical cyclones between 1977 and 2006, it has been observed that the most exposed territories comprise the totality of the Caribbean or Atlantic coast: the entirety of Belize, a large part of Honduras and Nicaragua, and northern Costa Rica. However, Caribbean hurricanes draw, or pull, the Inter-Tropical Convergence Zone (ITCZ) towards northern Central America, thereby provoking "storms" (a number of days of heavy rain or large amounts of accumulated rainfall), floods and landslides in areas that are larger than those affected directly by the hurricane; this is what happened with Hurricane Mitch. Similarly, storms and hurricanes originating in the Pacific Ocean are now taking a serious toll on Central America, when, previously, their trajectory was more to the north. Tropical depressions and storms that are not hurricane-category are also bringing heavier rainfall, such as Tropical Depression 12-E, which severely damaged El Salvador and parts of Guatemala, Honduras and especially Nicaragua.

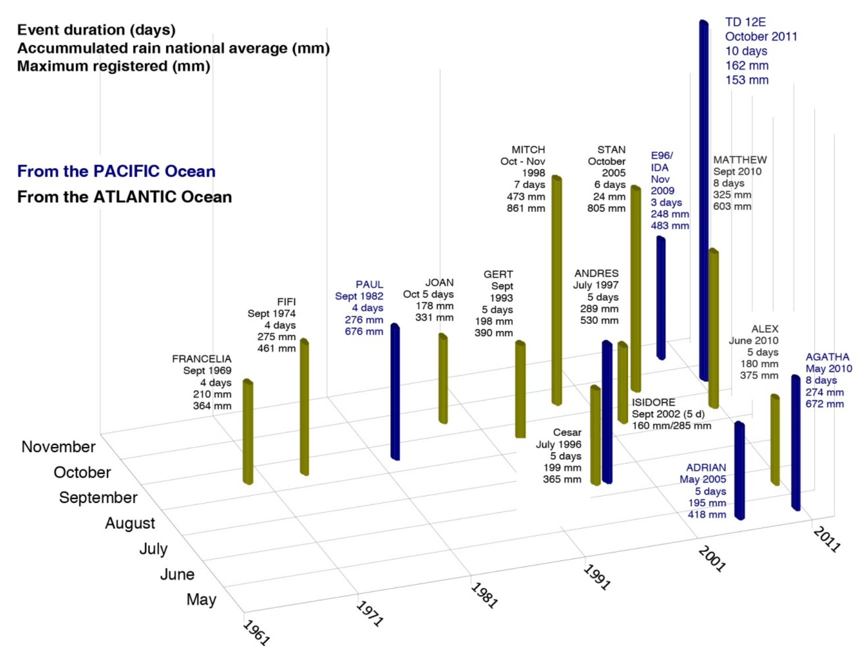
FIGURE 8
ATLANTIC OCEAN: NUMBER OF STORMS BY DURATION (MODERATE AND SHORT), 1878-2006
By five-year periods, moderate (blue), short (orange)



Source: NOAA, 2010.

Figure 9 illustrates the situation in El Salvador, demonstrating the increase in hurricanes, cyclones and other systems that originated in the Caribbean, and the novelty of extreme events originating in the Pacific.

FIGURE 9
EXTREME HYDRO-METEOROLOGICAL EVENTS IN EL SALVADOR, 1961-2011



Source: Ministry for Environment and Natural Resources of El Salvador, 2011.

Records show that the frequency of tropical storms of short duration (less than two days) in the Atlantic Ocean has increased, mainly since 1960. The possible relationship between this trend and

the possible effects of climate change and a higher concentration of precipitation is a potential line of analysis. The frequency of storms of moderate duration (five days) is possibly undergoing a multidecadal fluctuation, as the trajectory of these storms has changed since 1980. The IPCC's Fourth Report (2007b) does not yet make any assertions regarding the relationship between the frequency of these events and climate change, stating that it will be easier to identify once it is established whether the frequency strays from its historic oscillation in the coming years and decades.

With regard to the relationship between intensity of events and climate change, evidence is stronger. It is estimated that oceans have absorbed approximately 20 times more heat than the atmosphere during the last 50 years, giving rise to higher temperatures in both surface and deep waters (Barnett and others, 2005; Levitus, Antonov and Boyer, 2005). Both factors have contributed to tropical cyclones of greater intensity on the oceans (Hansen, 2005). This hypothesis is based on research that has found a positive relationship between the intensity of tropical cyclones and the surface temperature of the oceans (Emanuel, 1987; Holland, 1997; Henderson-Sellers and others, 1998; Zeng, Wang & Wu, 2007). As mentioned previously, the surface temperatures of the Pacific Ocean and the Caribbean Sea, both bodies of water that influence the climate in Central America, have been rising over the last 100 years. With regard to the future, international scientific literature suggests that hurricane intensity could increase by 5% to 10% during this century (CEPAL, CCAD/SICA, UKAID, DANIDA, 2011a).

German Watch's global climate risk index classifies the impacts of extreme events (storms, floods, temperature extremes and heat and cold waves) in a ranking of 183 countries, in which the lowest ranking country is the most vulnerable. Results for the period 1992-2011 show that Honduras was the most affected, followed by Nicaragua (third), Dominican Republic (tenth), Guatemala (eleventh), El Salvador (fifteenth), Belize (twenty-sixth) and Costa Rica (sixty-second). Due to the increase in extreme events in recent years, Central American countries are often among the ten most affected countries for the period 2004-2011: Dominican Republic was second in 2004, Guatemala was first and Honduras was seventh in 2005, Nicaragua was third in 2007, Belize was ninth in 2008, El Salvador was first in 2009, Guatemala was second and Honduras was fifth in 2010, and El Salvador was fourth and Guatemala was ninth in 2011 (Harmeling, 2012).

A third line of analysis looks at rainfall. International experts believe that while it has been relatively easy to analyse attribution in the case of temperature extremes, doing so with hydro-meteorological events is very complex and presents greater uncertainty. In its special report on extreme events, the IPCC indicates that changes in extremes can be associated with changes in averages, variability and probability distributions, or all of these factors combined. The report points out that natural variability will continue to be an important factor for future extreme events, in addition to changes associated with anthropogenic activities (IPCC, 2011).

In order to analyse precipitation variability in the region, the study used daily accumulated rainfall data from the period 1970-2011, recorded by select meteorological stations distributed throughout the Central American countries (the exact period may vary by station). The study looked at the following in order to analyse precipitation intensity and extreme precipitation events: daily accumulated precipitation, annual accumulated precipitation compared to ENSO periods (El Niño, Neutral and La Niña), number of days of rain per year, accumulated precipitation due to storms of short (less than two days), moderate (five days) and long (ten days) duration. To date, the study has analyzed data provided by three stations in El Salvador, seven stations in Honduras and eight

stations in Guatemala. The following section presents the results from four of these stations: Ilopango in El Salvador, Tegucigalpa and Tela in Honduras, and the National Institute of Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH) in Guatemala City, Guatemala.

EL SALVADOR: ILOPANGO STATION

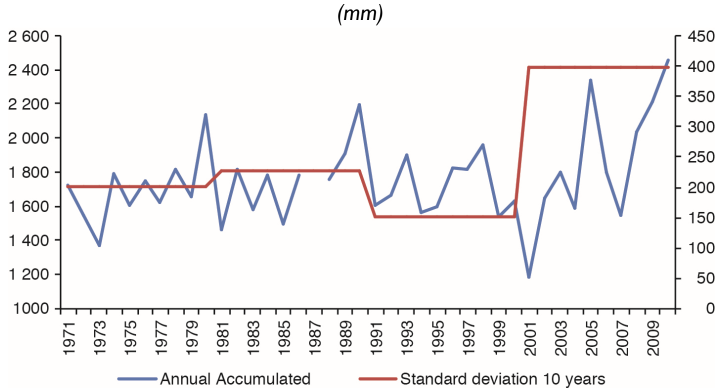
Ilopango is located 10 km to the east of San Salvador, on both flat and hilly land on the Pacific watershed. The area has a warm climate with hot, tropical savannah vegetation. It experiences an average annual precipitation of 1765 mm. Ilopango is located 615 m above sea level (AMSL) at 13° 41′ N, 89° 07′ W.

Figure 10 shows the annual accumulated precipitation at Ilopango station in blue and the standard deviation for each ten-year interval in red. It is possible to see that standard deviation per decade has gradually increased, except in the 1990s when it decreased. This means an increase in annual precipitation per decade between 1971 and 2010.

The possible existence of a trend or increases in climate variability is analyzed using different statistical tests that determine whether changes in precipitation averages or variance recorded between 1971 and 2010 are statistically significant. Statistical inference based on the use of these tests is subject to assumptions of independence, normality and homogeneity, which are hard to prove in most cases, and these results should therefore be treated with caution.

The results of the test for equality of variances in precipitation per decade indicate that changes have been significant, i.e. the annual accumulated precipitation recorded at Ilopango station has shown increased variability during the period 1971-2010.

FIGURE 10
EL SALVADOR, ILOPANGO: ANNUAL ACCUMULATED PRECIPITATION AND STANDARD DEVIATION, 1971–2010
(mm)



Source: Prepared by the authors with data provided by MARN.
Note: The year 1987 was not included due to incomplete daily records.

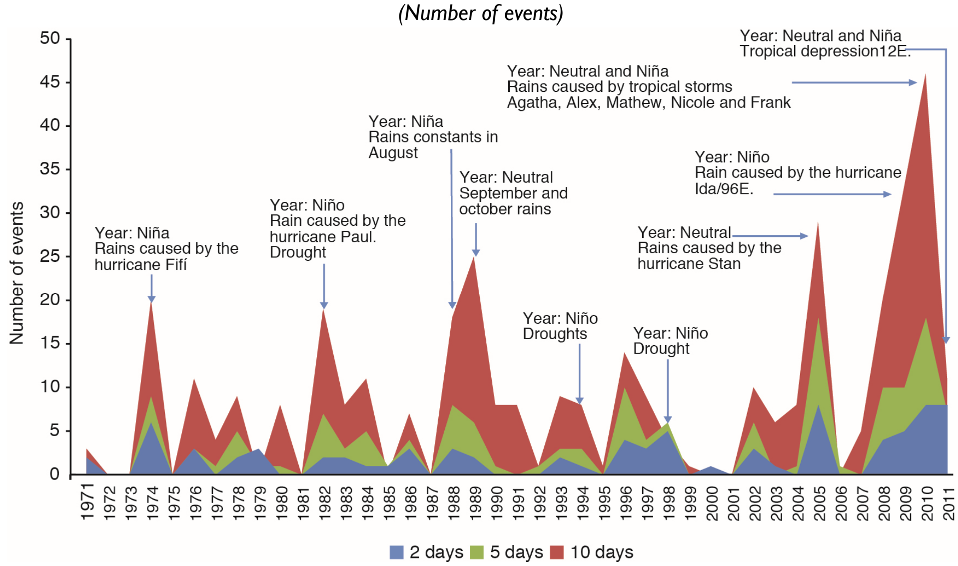
Based on the results of different tests, it is possible to conclude that changes in the mean annual accumulated precipitation are not statistically significant, although this variable has increased over the last decade. The average number of days of rain remained stable over the same period,

suggesting that there was a greater amount of precipitation during the last decade; this means that precipitation fell on the same number of days, but with significantly greater variability.

Additional analysis involved observing the behaviour of rain intensity and its evolution over time. Using daily precipitation records from the station, the amount of accumulated rain was measured over periods of two, five and ten consecutive rainy days, i.e. the quantity of rain was summed for consecutive days (even when there was no precipitation) for all 365 days of the year. There is overlapping in the counting since the first value for two days of consecutive rain equals the sum of the amounts on the first and second days, the second value for two days of consecutive rain equals the sum of the amounts on the second and third days, and so on. This is also the case with the values for the five- and ten-day periods. Thresholds of 100 mm, 150 mm and 200 mm of precipitation were applied to the periods of two, five and ten rainy days respectively; these periods represent events of short, moderate, and long duration. Results are shown in Figure 11 and Table 1.

Figure 11 shows that, historically, there were between 0 and 5 events with more than 100 mm of rain over two consecutive days, but that the average has increased over the last decade. The number of events with more than 150 mm over five consecutive days has reached up to 10 per year, and there is a positive trend of historical highs of accumulated rainfall from 2005 onwards. Finally, the number of events lasting ten days with more than 200 mm of precipitation shows a clear positive trend with regard to frequency and peaks over the last ten years, mainly due to hurricanes and tropical storms.

FIGURE 11
EL SALVADOR, ILOPANGO: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1971-2011
(Number of events)



Source: Prepared by the authors with data provided by MARN.
Note: Drought events were obtained from EM-DAT (2011) records. The year 1987 was not included because of incomplete daily records. The year 2011 includes information up to October 31. The thresholds correspond to 100, 150 and 200 mm accumulated over 2, 5 and 10 consecutive days respectively.

Table 1 shows that the number of events of short duration (two days) with more than 100 mm of rain remained relatively constant between 1971 and 2000, but then doubled in the last decade. The number of events of moderate duration (five days) experienced greater variability between 1981 and 1990; the number increased with respect to the previous decade, then decreased in the 1990s, and

finally doubled in the last decade. The number of events of long-duration (ten days) showed the same trend as those of moderate duration during the first few decades analyzed, but reached 168 days of rain by the last decade, three times higher than in the 1970s. This last figure is indicative of the high number of extreme events that have taken place in the region and brought more rain than the seasonal norm. Some examples of these extreme events are hurricanes Isidore (2002), Stan (2005), Ida/E96 (2009), Agatha, Alex and Matthew (2010), and tropical depression 12-E (2011).

TABLE 1
EL SALVADOR, ILOPANGO: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1971-2011
(Number of events)

	2 days of rain	5 days of rain	10 days of rain
1971-1980	16	20	55
1981-1990	14	35	97
1991-2000	16	27	55
2001-2011	37	71	168

Source: Prepared by the authors using data provided by MARN.
Note: The year 1987 was not included because of incomplete daily records. The year 2011 includes information up to October 31st. The 2001-2011 time period includes an extra year. The thresholds correspond to 100 mm, 150 mm y 200 mm accumulated over 2, 5 and 10 consecutive days respectively.

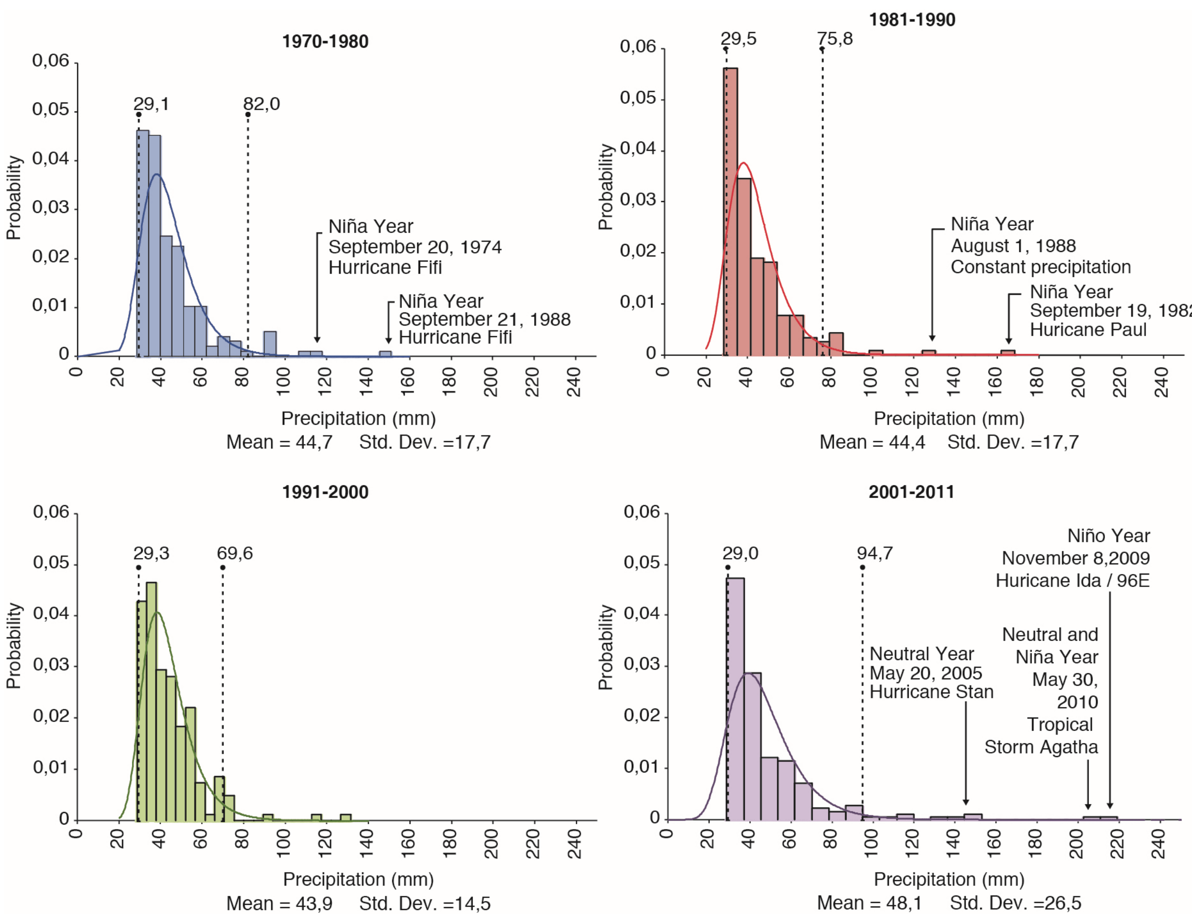
Recent studies have analyzed both the occurrence and behavior of extreme events with daily precipitation in several parts of the world. Guhathakurta and others (2010), Guhathakurta, Sreejith & Menon (2011), and Shukla, Trivedi & Kummar (2010) have analyzed the behaviour of precipitation extremes using a representative sample of stations in India and approximating the behaviour of this variable using a generalized extreme-value distribution. Chu and others (2009) have analyzed 24-hour accumulated precipitation that surpasses the established thresholds of 90^{th} and 99^{th} percentile in Hawaii, using a generalized extreme-value distribution. Other studies include those by Coles, Pericchi & Sisson (2003) in Venezuela, Overeem (2009) in the Netherlands, and Park & Jung (2002) in South Korea. The present analysis was preceded by a statistical analysis carried out by Lemus & Nerys (2011) in El Salvador.

This section analyzes the behavior of daily events with high levels of precipitation. For the purposes of this analysis, events whose daily precipitation levels were in the 95^{th} percentile were selected for each decade. These values matched the behaviour of a generalized extreme-value distribution. Figure 12 shows the distribution of event frequency; the continuous line represents the generalized extreme-value distribution. In general, it can be seen that there has been no increase in the intensity of extreme events on the very right of the distribution curve between 1971 and 2011. During the 1970s, the event with the highest recorded daily precipitation levels took place on September 20 and 21, 1974 (Hurricane Fifi), with 120 mm and 150 mm respectively, equal to 270 mm accumulated in 48 hours.

In the 1980s, the highest precipitation levels were reached in 1982 with Hurricane Paul and in August, 1988, during a period of constant rainfall; these events saw rainfall amounts of 170 mm and 130 mm, respectively. No specific events with extreme rainfall could be identified for the 1990s; however, records show highs of 120 and 131 mm. This past decade saw the highest levels of daily precipitation recorded for the period 1971-2011. These phenomena are linked to tropical storm Agatha (2010), Hurricane Ida/E96 (2009) and Hurricane Stan (2005), during which precipitation levels reached historical highs of 220 mm, 210 mm and 150 mm respectively.

The four charts in Figure 12 show an increase in variability in the daily manifestation of extreme precipitation. The maximum levels by decade increased from values of between 120 mm and 150 mm in the 1970s to extremes of 210 mm and 220 mm in the last decade. While the average value of historic daily extreme events did not change significantly, the standard deviation increased from 9.9 mm to 12.8 mm, according to the generalized extreme-value distribution. There were fewer extreme events with daily precipitation in the 1990s.

FIGURE 12
EL SALVADOR, ILOPANGO: 24-HOUR ACCUMULATED PRECIPITATION BY DECADE, 1970-2011



Source: Prepared by the authors with data provided by MARN.
Note: The last decade includes data up to October 2011.

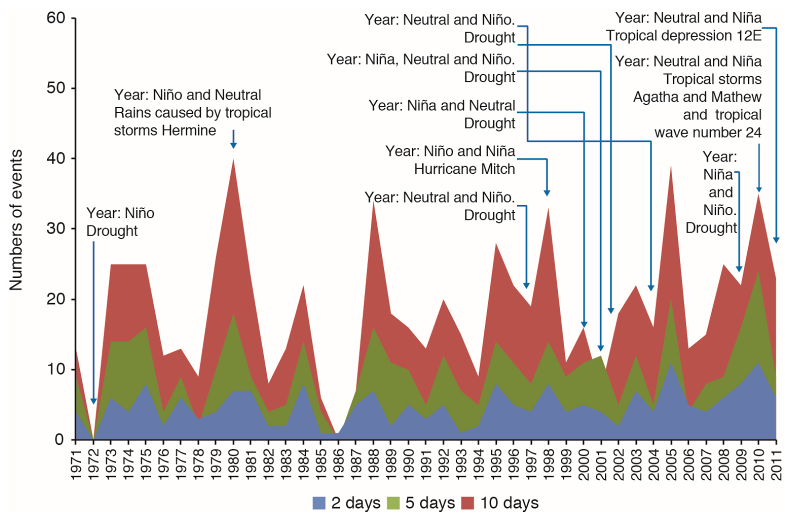
HONDURAS: TEGUCIGALPA STATION

Tegucigalpa is located at 14° 06′ N, 87° 13′ W in an area surrounded by pine forests in the Department of Francisco Morazán, which lies on a mountain range with heights between 935 m and 1463 m AMSL. The city has a tropical climate that is tempered by the altitude, meaning that it is less humid than the low valleys and coastal regions.

The results of various tests suggest that annual precipitation records from Tegucigalpa station have shown stable behaviour in terms of annual accumulated precipitation per decade during

the entire period 1971-2011. Likewise, precipitation variability and the number of rainy days (shown in Figure 13, Table 2) do not show significant changes over the ten-year intervals. The Tegucigalpa station stands out as having the lowest precipitation values of all stations in Honduras; therefore, it was decided to use thresholds of 50 mm, 75 mm and 100 mm for two, five and ten consecutive days of rain (corresponding to storms of short, moderate and long duration) respectively. One can observe that the number of events of short, moderate and long duration has increased, particularly during the last decade studied.

FIGURE 13
HONDURAS, TEGUCIGALPA: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1971-2011
(Number of events)



Source: Prepared by the authors with data provided by the National Meteorological Service of Honduras.
Note: The year 2011 includes information up to October 31st. The thresholds correspond to 50 mm, 75 mm and 100 mm accumulated in 2, 5 and 10 consecutive days.

TABLE 2
HONDURAS, TEGUCIGALPA: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1971-2011
(Number of events)

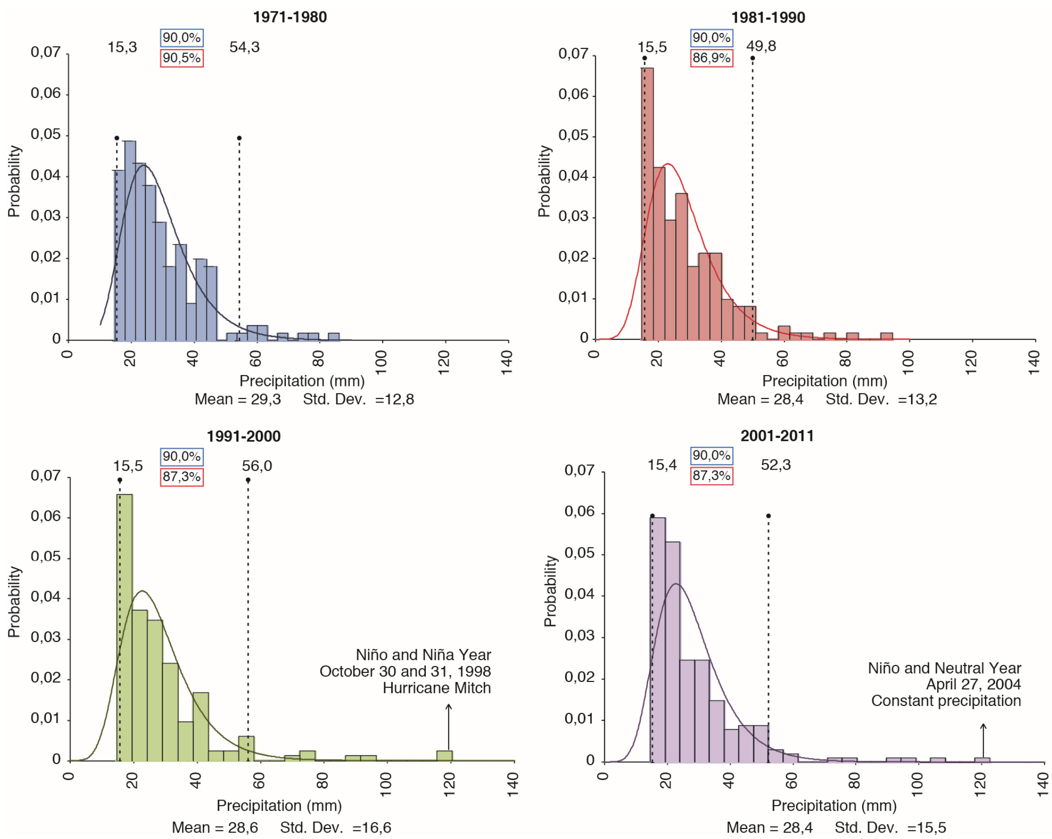
Period	2 days of rain	5 days of rain	10 days of rain
1971-1980	44	96	188
1981-1990	40	80	147
1991-2000	45	96	186
2001-2011	68	124	235

Source: Prepared by the authors with data provided by the National Meteorological Service of Honduras.
Note: The year 2011 includes information up to October 31st. The 2001-2011 time period includes an extra year. The thresholds correspond to 50 mm, 75 mm and 100 mm accumulated in 2, 5 and 10 consecutive days.

A significant portion of the analysis involved studying the intensity and number of extreme precipitation events recorded by meteorological stations. In order to do this, events with precipitation values in the 95th percentile were selected for each decade for each station. The resulting values were analysed using a generalized extreme-value distribution. The results show that the quantity and intensity of 24-hour accumulated precipitation extremes remained stable in Catacamas, Choluteca, La Ceiba and Yoro stations, while in Santa Rosa de Copán, Tegucigalpa and Tela, the values increased, as is shown at the right end of the distribution tail. The daily precipitation levels at Tegucigalpa station are low compared to other stations in that territory (see Figure 14). It is worth mentioning that none of the extreme precipitation records from La Ceiba station are associated with

extreme hydro-meteorological phenomena such as hurricanes or tropical storms; rather, all the extreme levels are associated with periods of intense precipitation in the region.

FIGURE 14
HONDURAS, TEGUCIGALPA: 24-HOUR ACCUMULATED PRECIPITATION BY DECADE, 1971- 2011

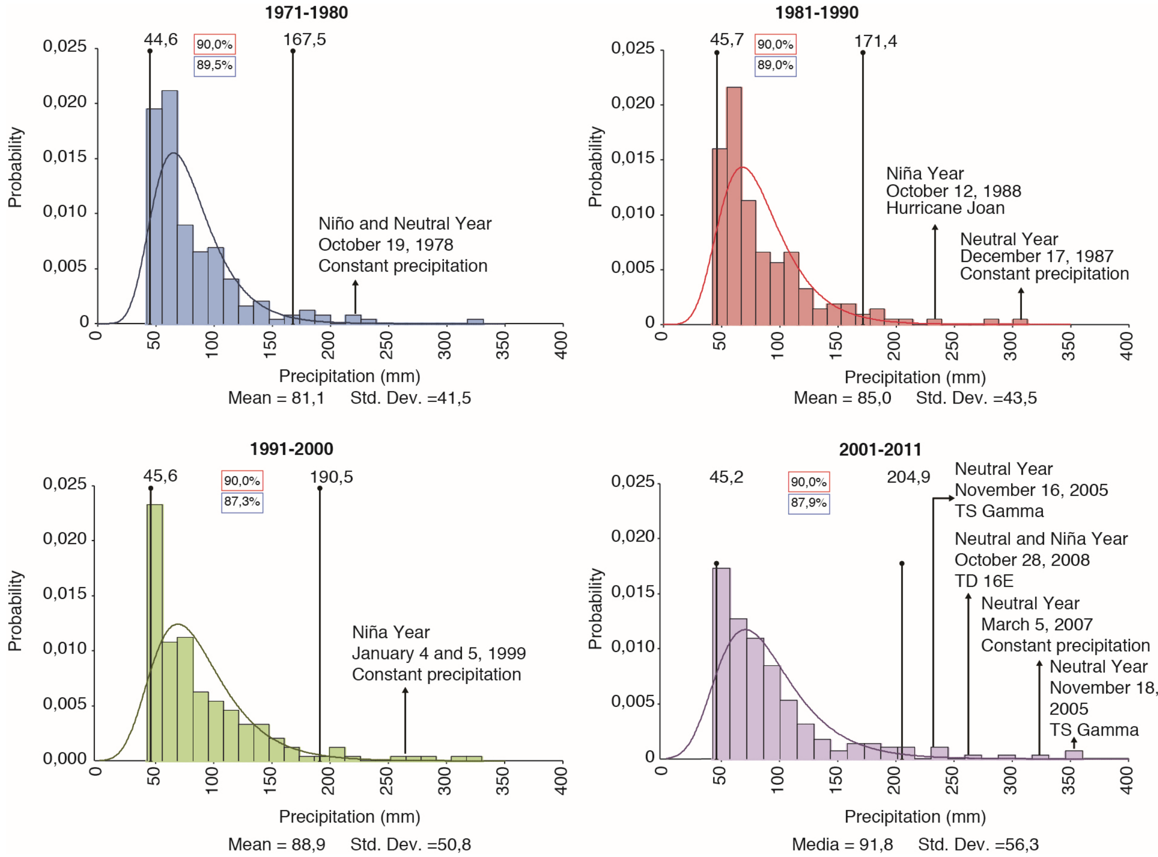


Source: Prepared by the authors with data provided by the National Meteorological Service of Honduras.
Note: The last decade includes data up to October 2011.

HONDURAS: TELA STATION

Tela is located at 15° 78′ N, 87° 45′ W, just 3 meters above sea level, in the Department of Atlántida on the Atlantic coast. It has a rainy tropical climate, except from December to March. Its annual average accumulated precipitation was 2925 mm during the period 1971-2010. It is important to highlight that there has been an increase in the average of the 95th percentile values (see Figure 15). During the 1970s, the average value was 81.1 mm; this value increased to 85 mm in the 1980s, 88.9 mm in the 1990s, and by the 2000s had reached 91.8 mm. The increase in variability of the recorded values, measured by standard deviation, is also of note. In the 1970s, standard deviation was 41.5 mm; it increased to 43.5 mm in the 1980s, 50.8 mm in the 1990s and 56.3 mm in the past decade. In other words, during the last decade, the average value and standard deviation reached their highest values in 40 years. Lastly, it is interesting to observe the increase in the range of values encompassed by the 90th percentile of recorded values (Figure 15); this range has broadened considerably during the period of study, from a range of 44.6 mm to 167.5 mm during the 1970s to 45.2 mm to 204.9 mm in the last decade.

FIGURE 15
HONDURAS, TELA: 24-HOUR ACCUMULATED PRECIPITATION, 1971 - 2011



Source: Prepared by the authors with data provided by the National Meteorological Service of Honduras.
Note: The last decade includes information up to October 2011.

GUATEMALA: INSIVUMEH STATION

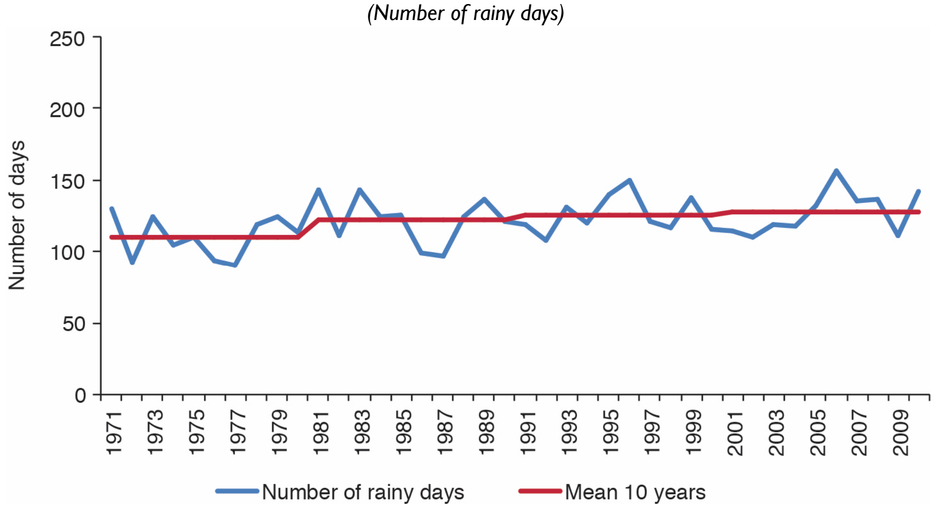
The INSIVUMEH station is located in Guatemala City, in the central region of the country, 14° 35′ N, 90° 32′ W, 1502 meters above sea level. Guatemala City is located in the Ermita valley and has a subtropical highlands climate (almost spring-like) throughout the entire year. Its precipitation ranged from 900 mm to 2000 mm (1196 mm on average) between 1970 and 2011. The results of various statistical tests indicate that average accumulated rain per decade and the number of rainy days have changed over time (see Figure 16), and that these changes are statistically significant.

The numbers of two, five and ten day-long events with values that surpass the proposed thresholds are shown in table 3. In all cases, a significant increase in the number of events has been observed, particularly in the past decade. The number of extreme events in the last decade is considerable, due to hurricane Stan (2005), tropical storm Agatha (2010) and even tropical depression 12-E (2011).

Accumulated precipitation for events of two, five, and ten days is shown in Figure 17. The highest number of two-day events with precipitation greater than the 100 mm threshold is five. There has been an increase in the frequency of events with accumulated precipitation since 2005. The

number of five-day events with rainfall values above 150 mm has fluctuated significantly. The greatest accumulation of rain for two, five, and ten day-long events occurred in 2010 and was the result of the tropical storms Agatha and Hermine.

FIGURE 16
GUATEMALA, INSIVUMEH: NUMBER OF DAYS OF RAIN AND AVERAGE, 1971–2011
(Number of rainy days)



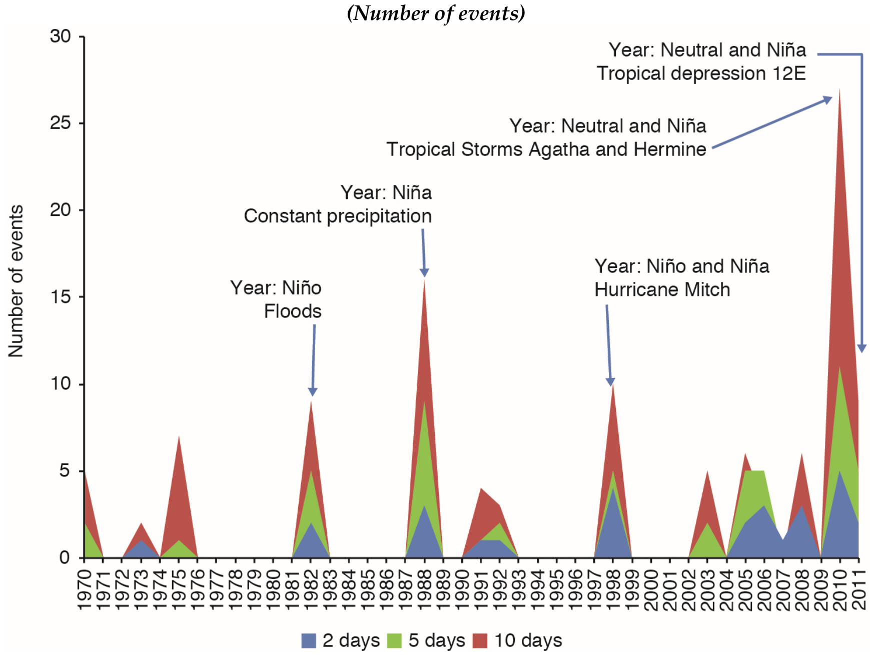
Source: Prepared by the authors with data provided by INSIVUMEH.

TABLE 3
GUATEMALA, INSIVUMEH: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1971-2011

Period	2 days of rain	5 days of rain	10 days of rain
1971-1980	1	1	9
1981-1990	5	14	25
1991-2000	6	8	17
2001-2011	10	30	56

Source: Prepared by the authors with data provided by INSIVUMEH.
Note: Data for 2011 includes data until October 31st. The period 2001-2011 includes an extra year.
The thresholds correspond to 100 mm, 150 mm y 200 mm accumulated over 2, 5 y 10 consecutive days.

FIGURE 17
GUATEMALA, INSIVUMEH: NUMBER OF EVENTS SURPASSING THRESHOLDS, 1970-2011
(Number of events)

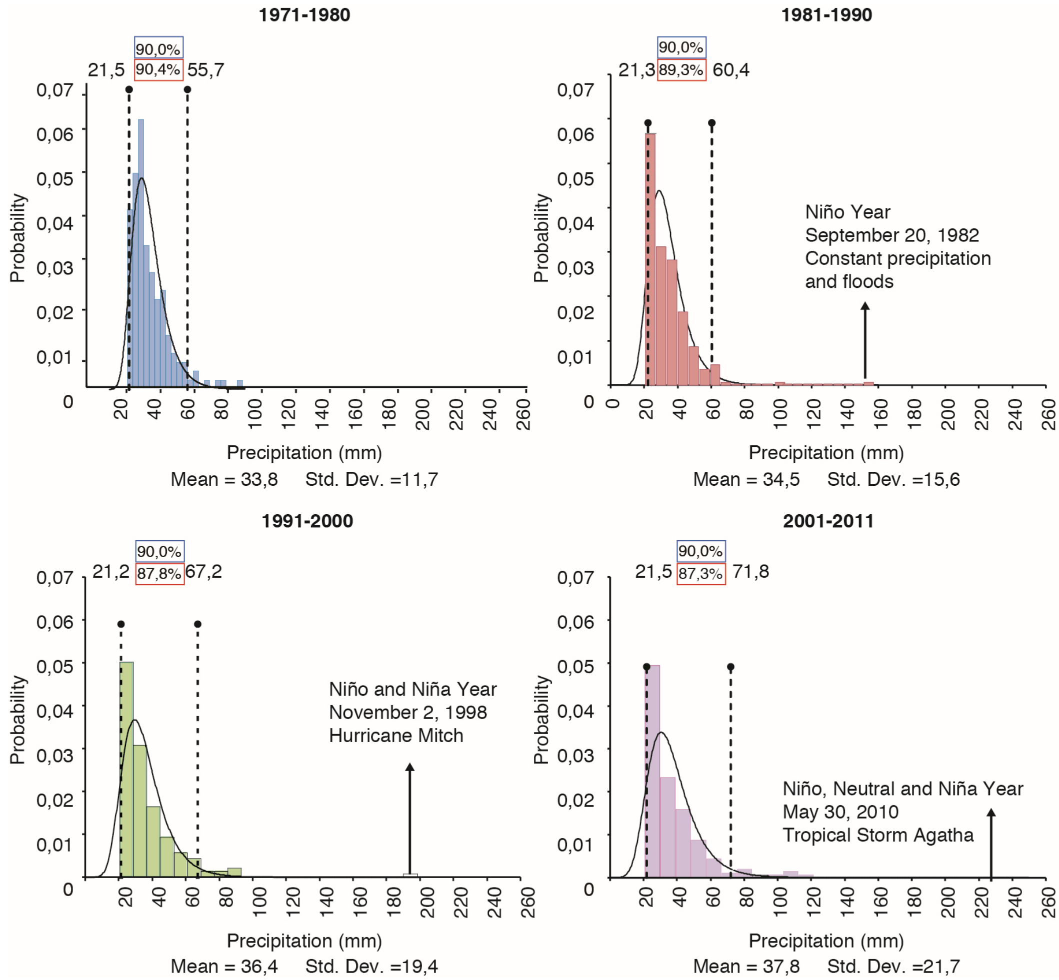


Source: Prepared by the authors with data provided by INSIVUMEH.
Note: Drought events were obtained from EM-DAT (2011) records. Data for 2011 includes data until October 31.
The thresholds correspond to 100 mm, 150 mm y 200 mm accumulated over 2, 5 y 10 consecutive days.

Daily events with precipitation values in the 95th percentile were analysed using a generalized extreme-value distribution of all precipitation values. Figure 18 shows event frequency distribution by decade; the continuous line represents the generalized extreme-value distribution. Analysis of the period 1971-2011 shows an increase in the intensity of extreme events, which can be seen on the far right of the distribution. In the 1970s, the maximum level of precipitation was 90 mm. In the 1980s, the maximum level of precipitation occurred on September 20, 1982 (157 mm) and was related to intense rains and flooding. In the 1990s, the maximum precipitation level (200 mm) occurred on November 2, 1998, due to hurricane Mitch and the heavy rains associated with it. In the last decade, the highest level of precipitation occurred on May 30, 2010 due to tropical storm Agatha, reaching a historical high of 220 mm. The four charts comprising Figure 18 indicate that both the average and variance of these daily extreme precipitation events have increased; maximum levels by decade increased from less than 100 mm in the 1970s to extremes of 220 mm in the last decade.

To summarize, there is evidence of a significant increase in the frequency of extreme events, such as floods, storms and hurricanes in Central America. Science indicates that the temperature increase of Central American land masses and the surrounding oceans should give rise to greater evaporation, more extreme accumulated precipitation events and more intense hurricanes, and the intensity of the rains being experienced by the region confirm this. Groups of international experts are now formulating methods for determining the relationship between climate change and extreme events, and even between climate change and just one specific event. Therefore, in Central America, the hypothesis that the increase in number of extreme events is partly attributable to climate change beyond natural climate variability is worthy of consideration and it is proposed that this type of technical analysis continue to be undertaken by regional experts and international partners.

FIGURE 18
GUATEMALA, INSIVUMEH: 24-HOUR ACCUMULATED PRECIPITATION, 1971-2011



Source: Prepared by the authors with data provided by INSIVUMEH.
Note: The last decade includes data up to October 2011.

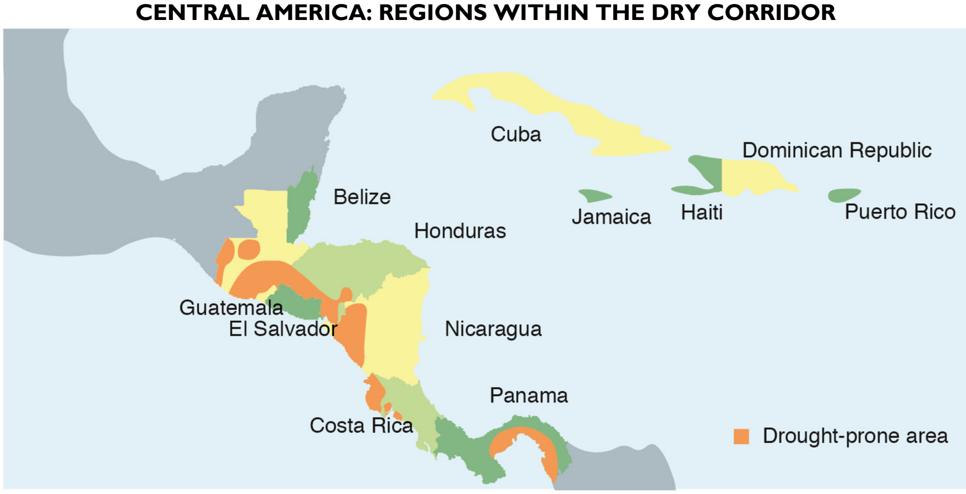
Climate change could be considered a phenomenon that will only have an effect in the distant future and that cannot be addressed right now due to budgetary restrictions worsened by the current global recession, as well as existing social and economic needs. However, evidence of changes in the climate and current growing impacts of extreme events such as tropical depression 12-E prove that urgent measures need to be taken. At the same time, the growing threat of even worse impacts and costs in the future means that these reconstruction measures should be different than in the past; they need to consider changes in infrastructure standards, efforts to protect river basins and natural coastal barriers such as mangroves, efficient water management that takes into account the design and location of homes, social infrastructure and communities, among many other possible measures. Such an investment would reduce both vulnerability and the costs associated with future extreme events, while simultaneously building greater resistance to the worse impacts that are estimated to gradually result from climate change.

3. POTENTIAL IMPACTS ON ARIDITY AND DRY MONTHS

Within the framework of this initiative, the study of potential impacts on aridity and dry months in the region seeks to estimate the possible consequences for agricultural production, hydroelectric power generation, human consumption of water, and ecosystems with high humidity requirements, such as the tropical lower montane wet forest (ECLAC, COSEFIN, CCAD/SICA, UKAID, DANIDA, 2012b). The analysis benefited from collaboration with partners from the Global Mechanism of the United Nations Convention to Combat Desertification (GM-UNCCD) in the selection of methodology and the preparation of exploratory studies.

Central America is home to an area known as the "dry corridor" which is more arid than the rest of the region. This corridor, along with other areas, has been gravely affected by periods of drought. The dry corridor encompasses areas in all the countries in the region, but the majority of the corridor is located on the Pacific watershed (MARENA, 2001; Ramírez, 1983; ECLAC, 2002). Between 1974 and 2004, Guatemala, Honduras, Nicaragua, the Pacific coast of Costa Rica and the Atlantic coast of Panama experienced the greatest concentration of drought events. The most severe droughts have occurred in the eastern territories, in the departments of Alta Verapaz and part of El Petén, Guatemala; the north of Cortés department and the northwest of Gracias a Dios, Honduras; Rivas department, Nicaragua; and the north of Guanacaste province, Costa Rica. Droughts are associated with environmental degradation, which, combined with adverse climatic conditions, increases drought recurrence and dryness. El Niño (ENSO) typically causes significant losses in all of the countries in the region, and these losses could be exacerbated by the estimated effects of climate change (PNUMA, PNUD, EIRD, World Bank, 2010).

MAP 5
CENTRAL AMERICA: REGIONS WITHIN THE DRY CORRIDOR



Source: Regional Climate Change Strategy, CCAD y SICA 2010, P. Ramírez, 2007.

A particularly severe drought occurred in 2001, resulting in a significant decrease in rainfall between June and August. This had many repercussions, including impacts on agricultural production, hydroelectric power generation, availability of drinking water and food security. It is recommended that strategies to adapt to drought incorporate the medium- and long-term threats of climate change (ECLAC & CCAD, 2002).

Drought is an extreme phenomenon characterized by a scarcity of rainfall relative to the historical average of a given geographical region. Drought presents a risk in semi-arid, semi-humid and humid areas, the last two tending to historically characterize most of Central America. In such regions, the soil and subsoil are not usually subject to a lack of water for an extended time during the period of plant-growth; by contrast, precipitation is already scarce or non-existent in arid and hyper-arid regions. The impact of drought on the environment is evident in the acceleration of desertification, which increases the risk of fires and limits the availability of water for domestic and industrial uses. Unlike floods, whose impacts are felt in a short period of time, the effects of droughts can be hard to assess for months or years (White & Walcott, 2009). Climate diversity also makes it difficult to compare droughts on a global scale. The research carried out by Fleig and others (2006), Van Lanen and Tallaksen (2007), and Sheffield and others (2009), among others, demonstrates the difficulty of using only one drought indicator on a global scale.

Meteorological drought is characterized by a lack of precipitation, which is often accompanied by potentially higher than normal levels of evapotranspiration over a long period of time over an extensive area of land (Tallaksen and Van Lanen, 2004). Agricultural drought occurs when soil humidity is not sufficient to support the growth of certain crops. Since each crop has individual phenological characteristics, it is not possible to adopt a single indicator that applies to even one geographical area (Marcos, 2001). Hydrological drought usually refers to situations in which water levels for various bodies of water are lower than normal (Tallaksen and Van Lanen, 2004, Fleig, 2004). Socioeconomic drought is characterized by a reduced availability of water that harms the economy and the population.

Aridity and drought can occur in the same geographical area, but they are different phenomena. According to the National Weather Service of the NOAA, "Drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage […]" Drought can occur relatively frequently as part of natural climate variability, but its intensity and duration can be affected by human activities, especially by deforestation, ecosystem degradation and climate change (White and Buchanan-Smith, 2005). When temperature, precipitation and phenomena such as ENSO undergo permanent changes, the affected areas can experience changes in aridity or in dry month patterns that go beyond drought as an extreme one-time event. However, these types of changes tend to be perceived as a prolongation and intensification of normal drought conditions. For this reason, research should be expanded to encompass possible future aridity trends.

This study analyses the evolution of aridity and intra-annual pattern of dry months by country, department and geo-climatic region, taking into account climate diversity and its disaggregation in order to formulate appropriate actions. The study estimates potential changes for the cut-off years 2020, 2030, 2050, 2070 and 2100 with respect to the historical reference period under two scenarios of climate change: a more pessimistic scenario (A2), and a less pessimistic one (B2). The study also expands upon previous analysis of temperature and precipitation by country and by year, which is available in the first chapter of the Technical report published in 2011 (ECLAC,

CCAD/SICA, UKAID, DANIDA, 2011a) and the study titled *The Economics of Climate Change in Central America: Potential Impacts on Intra-annual and Spatial Climate Patterns*, from the same 2012 technical series. Both reports were prepared by ECLAC with a technical team, and were revised and approved by ECCCA's Regional Technical Committee (RTC) in consultation with regional experts.

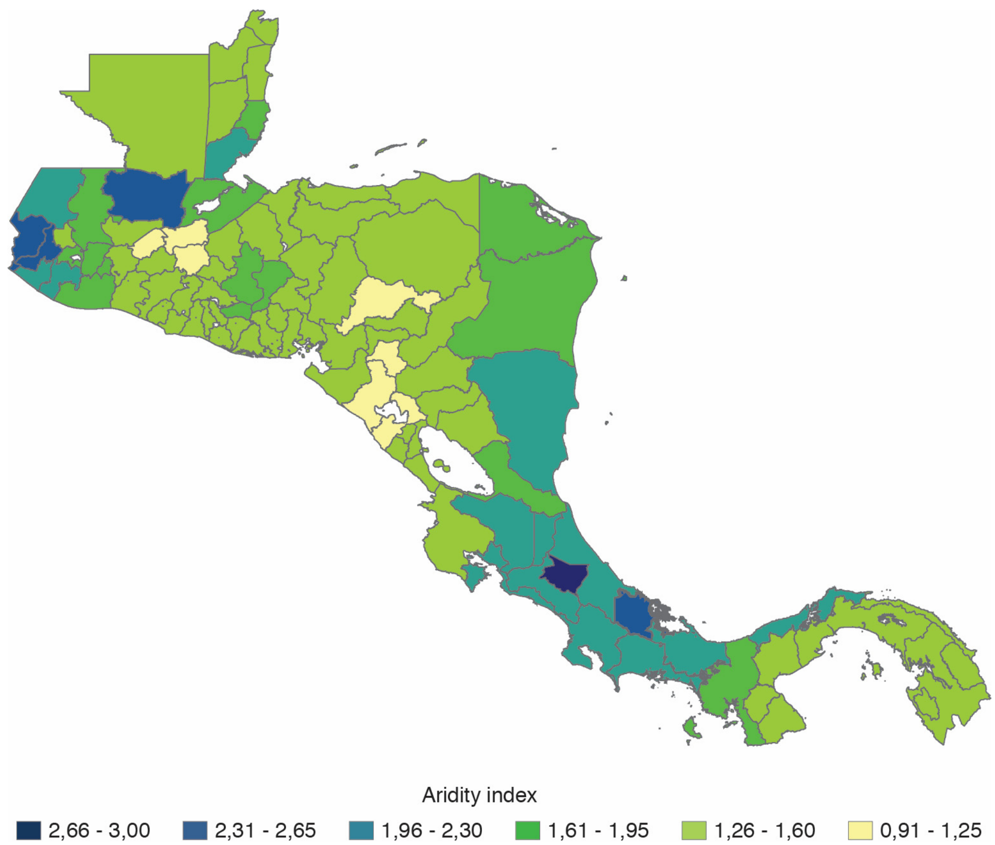
Aridity and dry month indicators were calculated using the "Methodological Guide for the Preparation of Maps of Arid, Semi-arid and Semi-humid Zones of Latin America and the Caribbean" (CAZALAC & PHI/UNESCO, 2005), as recommended by GM/UNCCD. The aridity index is used to delimit different climatic areas by dryness level, according to the criteria provided by Hassan and Dregne (1997) and the World Desertification Atlas (UNEP, 1997). This index expresses the relationship between input and loss of humidity. The first factor is mean precipitation and the second is the loss of evapotranspiration in the same period (CAZALAC & PHI/UNESCO, 2005). Results are presented by department, country and the four geo-climatic regions determined in collaboration with the RTC, national meteorologists and the CU/ECLAC. Since the study considers long-term scenarios that integrate various "layers" of analysis with uncertainties and methodological difficulties, the results should be interpreted as trends and relative magnitudes, and not as precise predictions or numbers.

The study uses average monthly temperatures (°C) and monthly accumulated precipitation (mm) by country and department, district or province, depending on the country. The historical analysis by department and geoclimatic region uses average annual temperature and accumulated-precipitation levels from the WorldClim database for the period 1950-2000. To estimate scenarios for the year 2100, the following models were used: ECHAM4 and HADCM3 (for scenario B2) and ECHAM4 and HADGEM (for scenario A2). To identify trends more clearly, the averages for ten-year intervals were calculated for each cut-off year: 2020 (2016-2025), 2030 (2026-2035), 2050 (2046-2055), 2070 (2066-2075) and 2100 (2091-2100). To distinguish humidity levels within the Central American region, it was decided to classify aridity index results in six categories starting with a lower value of 0.91 and ending with an upper value of 3.00, with intervals of 0.34 aridity index units. The departments that fall in the first category, with values between 0.91 and 1.25, are categorized as sub-humid-humid regions, whereas the rest of the categories are classified as humid regions to varying degrees, as shown in Map 6.

Temperature and precipitation levels for the period 1950-2000 generate an aridity index value of 1.6 for Central America and all its departments, resulting in its classification as a humid area, according to the international classification system. Part of Guatemala's Western Highlands, most of Costa Rica, and the western region of Panama (which comprises the provinces of Bocas del Toro, Chiriquí and the Ngöbe-Buglé region) are the regions with the highest index values. Aridity levels also vary by geoclimatic region: Guatemala's Western Highlands is the most humid, with an aridity index value of 1.96, followed by the Atlantic region (1.62), Central region (1.54), which has the greatest diversity of index values, and the Pacific region (1.53). The most arid departments, with the lowest aridity index value and classified as sub-humid-humid (i.e. within the 0.91 to 1.25 range) are León (1.23), Estelí (1.20), and Managua (1.14) in Nicaragua; El Paraíso (1.21) in Honduras; and Chiquimula (1.14), El Progreso (1.11), and Zacapa (1.05) in Guatemala. Even though there are different classifications, these departments are generally associated with the dry corridor of Central America. Other departments associated with this corridor fall in the 1.26-1.60 range.

According to the climate change scenarios, it is likely that the average temperature will increase by 2.5°C under scenario B2 and 4.2°C under scenario A2 by 2100, relative to the historical average for 1980-2000. Precipitation would decrease by 10.5% in B2 and 28.4% in A2[3]. Therefore, climate change would alter the region's humidity. Map 7 illustrates the evolution of calculated aridity index values for all departments in Central America up to 2100.

MAP 6
CENTRAL AMERICA: ARIDITY INDEX VALUES BY DEPARTMENT, 1950–2000 AVERAGE
(Aridity index units)



Source: Prepared by the authors.

Under the less pessimistic scenario (B2), the majority of departments would experience slight increases in aridity by 2020. There would be a slight reduction, within the range of 0 to 0.05 aridity index units, in only 19% of departments. Results indicate that under scenario A2, an even greater majority of Central America would experience slight increases in aridity. In the department of Alta Verapaz (central region) and Huehuetenango, Quetzaltenango, Quiché, and San Marcos (Guatemala's Western Highlands), the increase in aridity would be greater, with a change in index value in the range of -0.21 to -0.40.

Results for the 2030s show a trend of greater aridity relative to the historical period. Under scenario B2, only three departments would experience a slight decrease in aridity: Totonicapán,

[3] Reported values for the average of results from the general circulation models HADCM3, GFDL R30 and ECHAM4 for B2, and HADGEM1, GFDL CM2.0 and ECHAM4 for A2. See ECLAC, CCAD/SICA, UKAID & DANIDA, 2011.

Zacapa and El Progreso, Guatemala; the rest of Central America would see an increase, with changes in the range of -0.01 to -0.20. Under scenario A2, aridity would increase relative to the historical period, with changes within the range of -0.01 to -0.40. In Guatemala, the number of departments with growing levels of aridity would increase, with changes in the range of -0.21 to -0.40, including the departments of Baja Verapaz, Chimaltenango, Izabal, Sacatepéquez, Sololá and Totonicapan, as well as the five departments that will have already reached this range by 2020. The district of Toledo, Belize, would also see an increase in aridity within this range.

Towards 2050, under scenario B2, all of Central America would experience an increase in aridity relative to the historical period, with changes in the range of -0.01 to -0.20. Under scenario A2, 42% of departments would experience an increase in aridity in the range of -0.21 to -0.40 units. These departments are largely located in Guatemala, the Atlantic region of Belize, the Atlantic and central regions of Honduras, the central region of El Salvador, the Atlantic and central regions of Nicaragua, the central and Pacific regions of Costa Rica, and the Pacific region of Panama. Furthermore, Alta Verapaz, Huehuetenango, San Marcos y Quetzaltenango in Guatemala; Heredia and Limón in Costa Rica; and Bocas del Toro in Panama, would experience an increase in aridity, with changes in the range of -0.41 to -0.60. The province of Cartago, Costa Rica, would see the greatest increase in aridity, with changes in the range of -0.61 to -0.80.

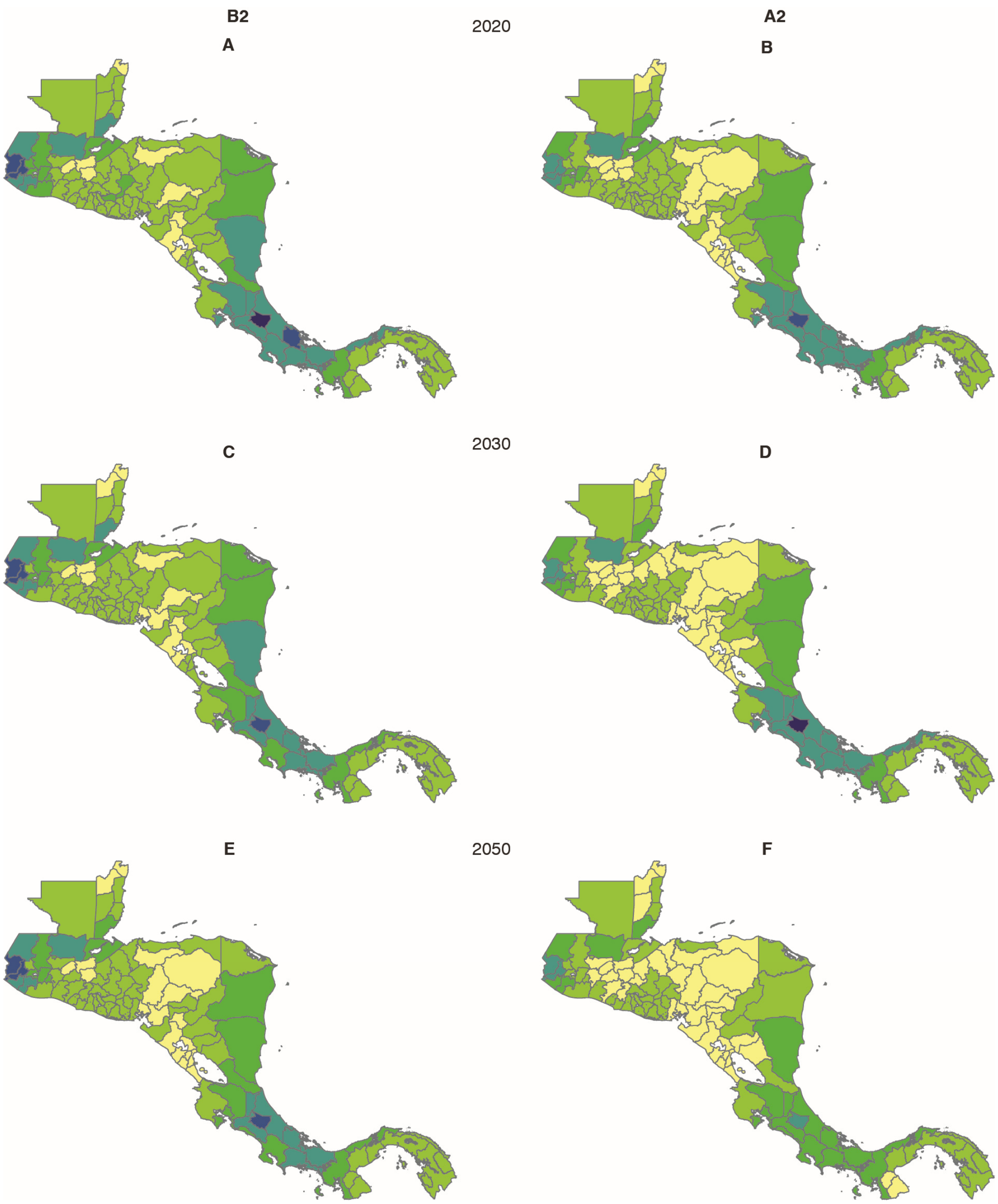
In the second half of this century, the rate of increase in aridity would increase under both scenarios. In B2, 61% of departments would see an increase in aridity with changes ranging from -0.01 to -0.20 units by 2100; 31% would experience an increase with changes ranging from -0.21 to -0.40, primarily in the Atlantic region, and to a lesser extent, in the central region and Western Highlands of Guatemala, as well as the Pacific coasts of Guatemala, Costa Rica and Panama. The regions with the greatest increase in aridity would be the central and Atlantic regions of Costa Rica, and Bocas del Toro, Chiriquí and the region of Ngöbe-Bugle in Panama, with index value changes in the range of -0.41 to -0.60 (5% of departments). Cartago, Costa Rica, would be the province with the greatest increase in aridity under scenario B2, with a decrease in index value of between -0.61 and -0.80.

Under scenario A2, conditions would be more severe. It is estimated that by 2100 only 12% of the departments will experience minor increases in aridity, i.e. decreases in index value of between -0.01 and -0.20 units. Three of them are located in Guatemala's dry corridor, and the rest are as follows: El Paraíso, Honduras; Estelí, León, Managua, Masaya, and Rivas, Nicaragua; and Los Santos and Darién, Panama. 54% of departments would experience increases in aridity corresponding to a decrease in index value of between -0.21 and -0.40; 22% would experience increases in aridity corresponding to a decrease in index value of between -0.41 and -0.60; 8% would experience increases corresponding to a decrease in index value of between -0.61 and -0.80; and 4% would see increases corresponding to a decrease in index value of between -0.81 and -1.00. The departments with the greatest increases would be Alta Verapaz (-0.85), San Marcos (-0.86) and Quetzaltenango (-0.90), Guatemala, and Cartago (-1.00), Costa Rica.

As a result, by 2100, Central America could experience levels of precipitation and temperature that translate into an average aridity index value of 1.4 in the less pessimistic scenario (B2), and 1.2 in the more pessimistic scenario (A2); this means changes of -0.2 and -0.4 units (i.e., higher aridity levels) with respect to the 1950-2000 period. Under scenario B2, the department of Quetzaltenango in Guatemala's Western Highlands would be the least arid area in the region, with a

maximum index value of 2.09, while the department of Zacapa, in the Atlantic region of Guatemala, would be the most arid area in the region, with a minimum index value of 1.01. Under scenario A2, the province of Cartago, Costa Rica, would be the least arid (1.78), while the department of Zacapa, Guatemala, would be the most arid (0.96).

MAP 7
CENTRAL AMERICA: ARIDITY INDEX VALUES BY DEPARTMENT, SCENARIOS B2 AND A2 UP TO 2100
(Aridity index units)



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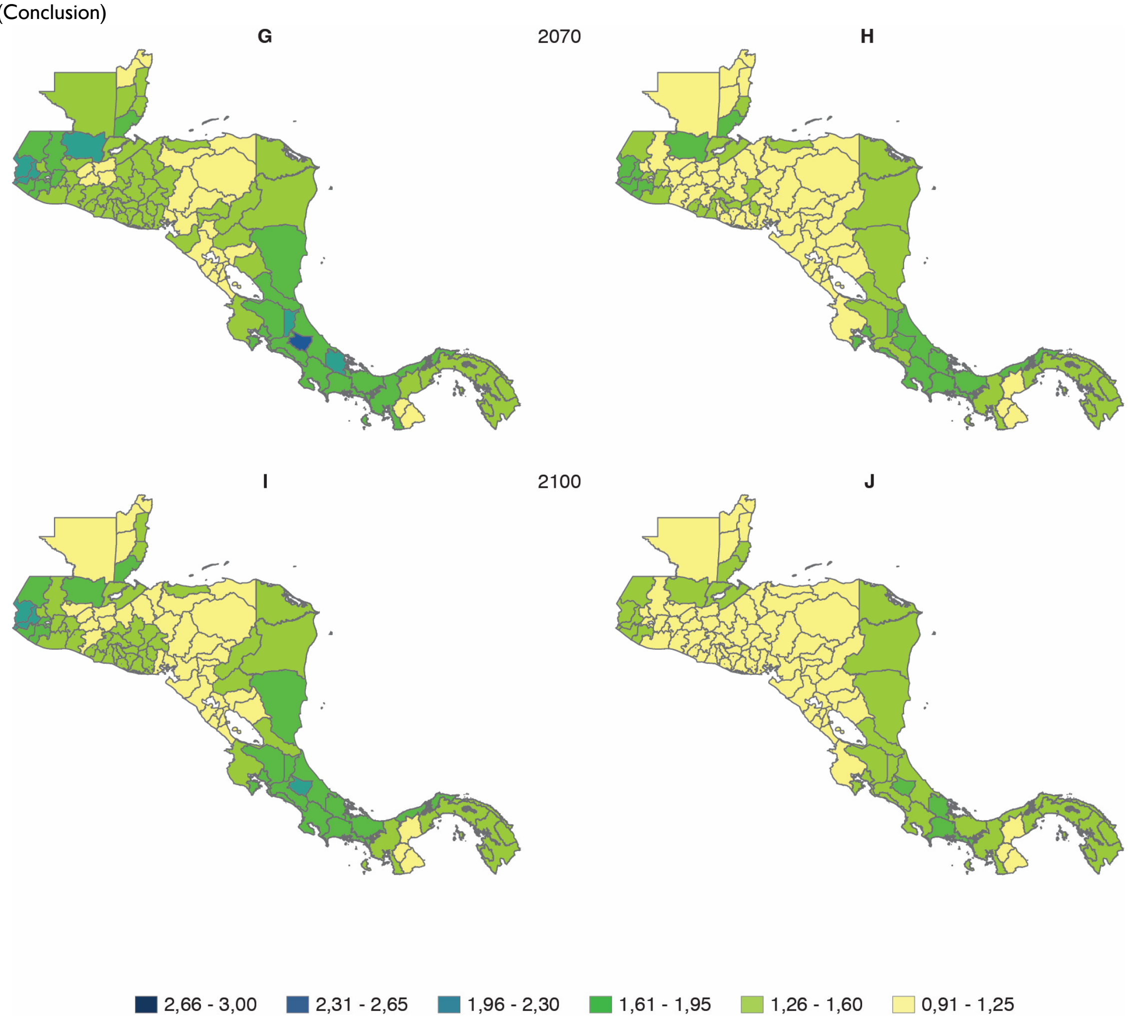
(Conclusion)



Source: Prepared by the authors.

Panama and Costa Rica will be the most humid countries in the Atlantic region with aridity index values of 1.51 and 1.75 respectively, and Guatemala and Belize will be the most arid countries with values ranging from 1.06 and 1.41, depending on the scenario. In the Pacific region, Guatemala and Costa Rica will be the most humid countries with values between 1.35 and 1.61, while Honduras and Nicaragua will be the most arid countries with values between 1.05 and 1.14. In the central region, Costa Rica will be the most humid country with values between 1.58 and 1.80, while Belize will be the most arid country with values between 1.09 and 1.20. The results suggest that Guatemala's Western Highlands would have a value of 1.69 under scenario B2 and 1.26 under scenario A2.

In general, it can be seen that the departments that will experience the greatest increases in aridity will be those that have historically been more humid. On the other hand, the departments with the highest aridity levels in the period 1950-2000 will experience the lowest increase in aridity during this century. At the same time, in absolute terms, those departments that have historically had the lowest levels of aridity will continue to have the lowest levels of aridity. Therefore, the relative distribution of regions with higher and lower aridity will be maintained, but there will be a generalized increase in aridity and this will be more severe under the more pessimistic scenario (A2)

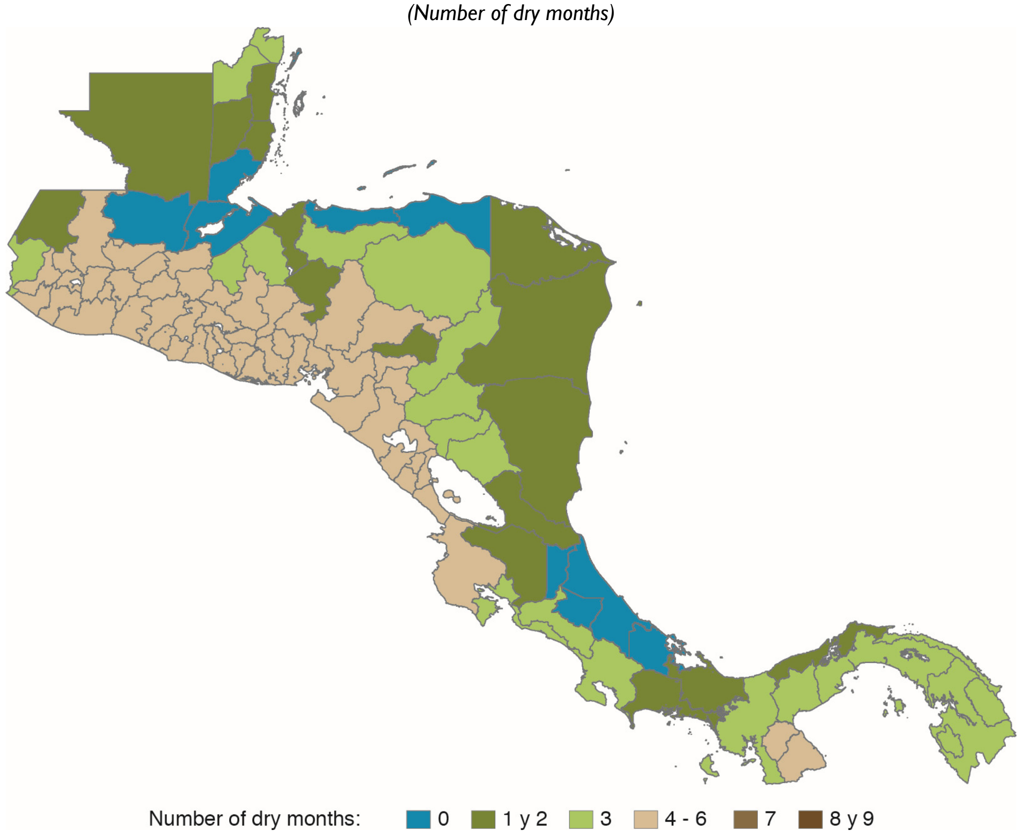
and in more humid regions. As a result, by the end of the century, the variation in index values between the climatic regions would decrease, especially under scenario A2, in which all four regions would have an aridity index value close to 1.2. This would mean increasing homogeneity in average aridity conditions throughout a large part of the region, similar to those experienced in the most arid segments of the dry corridor during the historical period.

The results presented in this section suggest that in the next two decades, there may be a trend of growing aridity, with some limited areas experiencing less aridity, followed by fluctuating but gradually increasing aridity, especially under scenario A2. Such changes could bring greater risks depending on the intra-annual distribution of precipitation, including rainy season onset, duration, stability, and end (including changes to the period known as the "dog days"). This section presents estimates of potential changes in these intra-annual variables. Specifically, this section analyses the number of dry months per year by department and geoclimatic region, comparing the historical average for the period 1950-2000 with estimates from the two climate change scenarios (B2 and A2) for the cut-off years 2020, 2030, 2050, 2070 and 2100. A dry month is one in which precipitation is less than 50% of evapotranspiration for that same month (CAZALAC & PHI/UNESCO, 2005). The analysis takes into account changes in intra-annual pattern (month by month) of the dry season by region and country.

During the reference period, the Pacific region had the highest number of dry months per year, ranging between four and six months, mainly in Guatemala, El Salvador, Honduras and Nicaragua. On the other hand, the Atlantic region had the lowest number of dry months. Historically, the district of Toledo in Belize, the departments of Alta Verapaz and Izabal in Guatemala, and Atlántida in Honduras, and the Atlantic region of Costa Rica, generally did not experience dry months. The rest of this region experienced between one and two dry months per year. Guatemala's central and Western Highlands regions have a more diverse climate, with a range of between one and six dry months per year. According to the historical average, no department experienced more than six dry months per year. Map 8 shows the number of dry months per year in each department, as an average for the period 1950 -2000, classified into six ranges.

In Central America, accumulated precipitation levels vary significantly from year to year, and intra-annual distribution varies with geography and time of year. Such changes can be particularly harmful (IPCC, 2007b). According to the results of another study from this technical series, *The Economics of Climate Change: Potential Impacts on Climate's Annual and Spatial Patterns*, it is likely that monthly precipitation patterns will change as a consequence of climate change. These changes are different for scenarios B2 and A2, and are related to the start, duration, and end of the rainy season and "dog days". These patterns will play an important role in determining the climatic conditions of the regions during sowing and harvesting periods. Other changes, such as a greater concentration of precipitation, can provoke floods and mudslides, and hinder water management, irrigation control, prevention of water erosion and dry farming.

MAP 8
CENTRAL AMERICA: NUMBER OF DRY MONTHS PER YEAR BY DEPARTMENT, 1950–2000 AVERAGE
(Number of dry months)

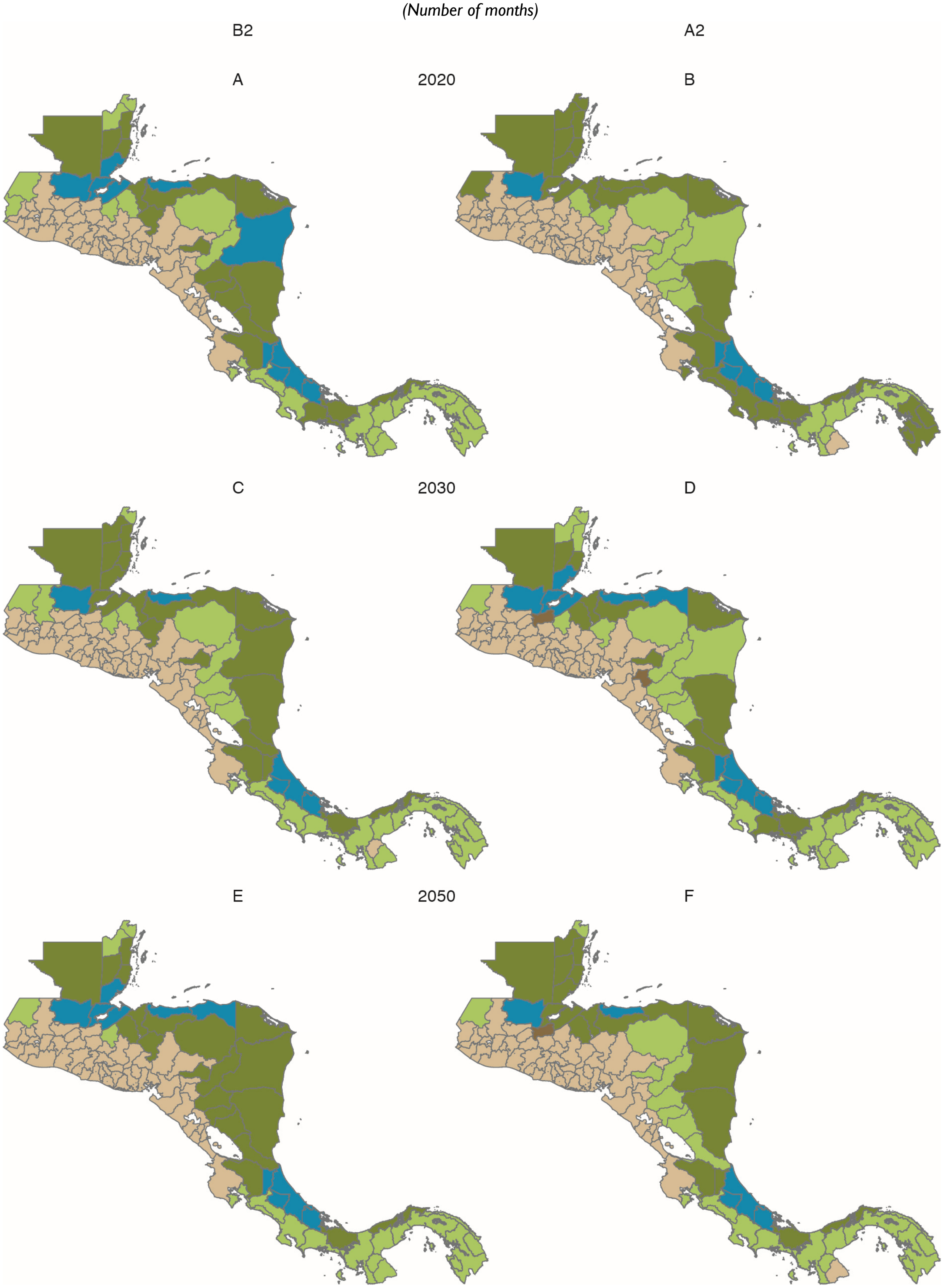


Source: Prepared by the authors.

Therefore, it is expected that climate change will bring about changes to the pattern of dry months in Central America. Average monthly temperature and accumulated precipitation values for the years 2020, 2030, 2050, 2070 and 2100[4], estimated using the IPCC's B2 and A2 scenarios, was used to estimate the pattern of the dry season and its duration and the area affected, using the dry month indicator (see Map 9). During the coming decades, the majority of departments will experience minor changes in the number of dry months in both scenarios, primarily due to fluctuating precipitation until 2030. It is possible that there will be greater variability both in increases and decreases in the number of dry months over the coming decades. Given that current variability, both inter- and intra-annual, gives rise to serious impacts on the region, it is of utmost importance that the capacity to adapt and manage risk in the short term be improved. As of 2050, there will be a more generalized trend of increases in the number of dry months and a gradual differentiation between the two scenarios, with A2 being the more severe of the two. Short term efforts to respond to climate variability and extreme events will be key to reducing losses in the short term and preparing the region for severe cumulative changes that could take place in the medium term.

[4] The years 2020, 2030, 2050, 2070 and 2100 refer to averages for periods of ten years: 2016-2025 (2020), 2026-2035 (2030), 2046-2055 (2050), 2066-2075 (2070) and 2091-2100 (2100).

MAP 9
CENTRAL AMERICA: NUMBER OF DRY MONTHS PER YEAR BY DEPARTMENT, SCENARIOS A2 AND B2 UP TO 2100
(Number of months)



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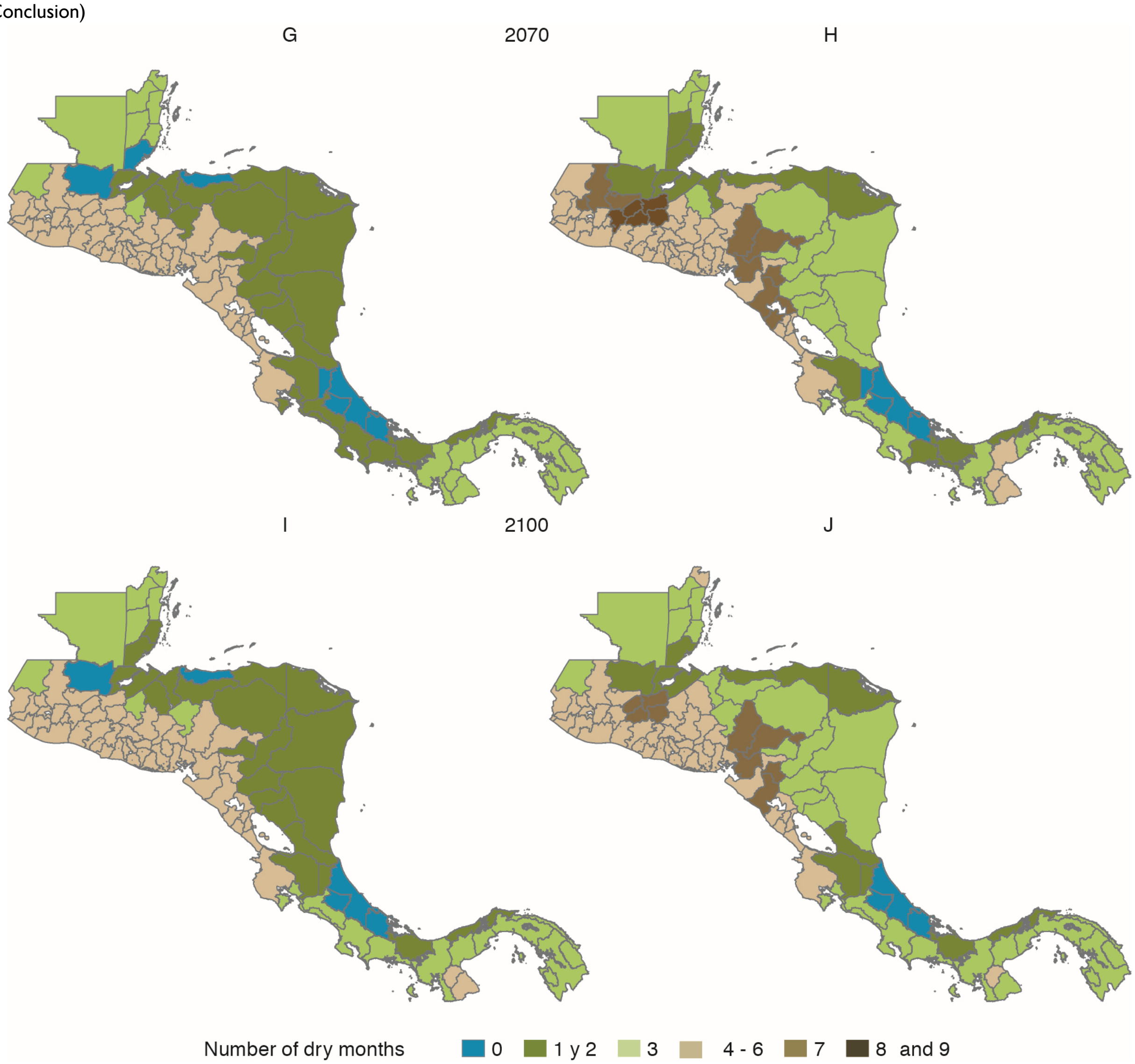
(Conclusion)



Source: Prepared by the authors.

Under scenario B2, until the year 2050, most departments would generally experience limited changes in terms of an increase or decrease in the number of dry months. In the long-term, more than a fifth of departments would see an increase in the number of dry months. By 2100, 28% of the region would experience an increase in the number of dry months, 27% would experience fewer dry months, and 45% would see conditions similar to historical ones. Under scenario A2, the changes would be more pronounced and, as of 2050, more severe. By 2050, the number of dry months would increase in 34% of the region, decrease in 6% and remain relatively stable in 60% with respect to the historical average. By 2100, 53% of the region would see an increase in the number of dry months, 8% would see a decrease and 39% would have conditions similar to historic ones. In this scenario, the provinces of Limón and Cartago in Costa Rica and Boca del Toro in Panama would be the only provinces without dry months by the end of the century. It is worth noting that there will be an increase in aridity in the majority of the departments on the Atlantic coast, primarily in those that currently have between one and two dry months, but in the future will have three. It is also worth mentioning that there will be an increase in the number of dry months in certain regions of

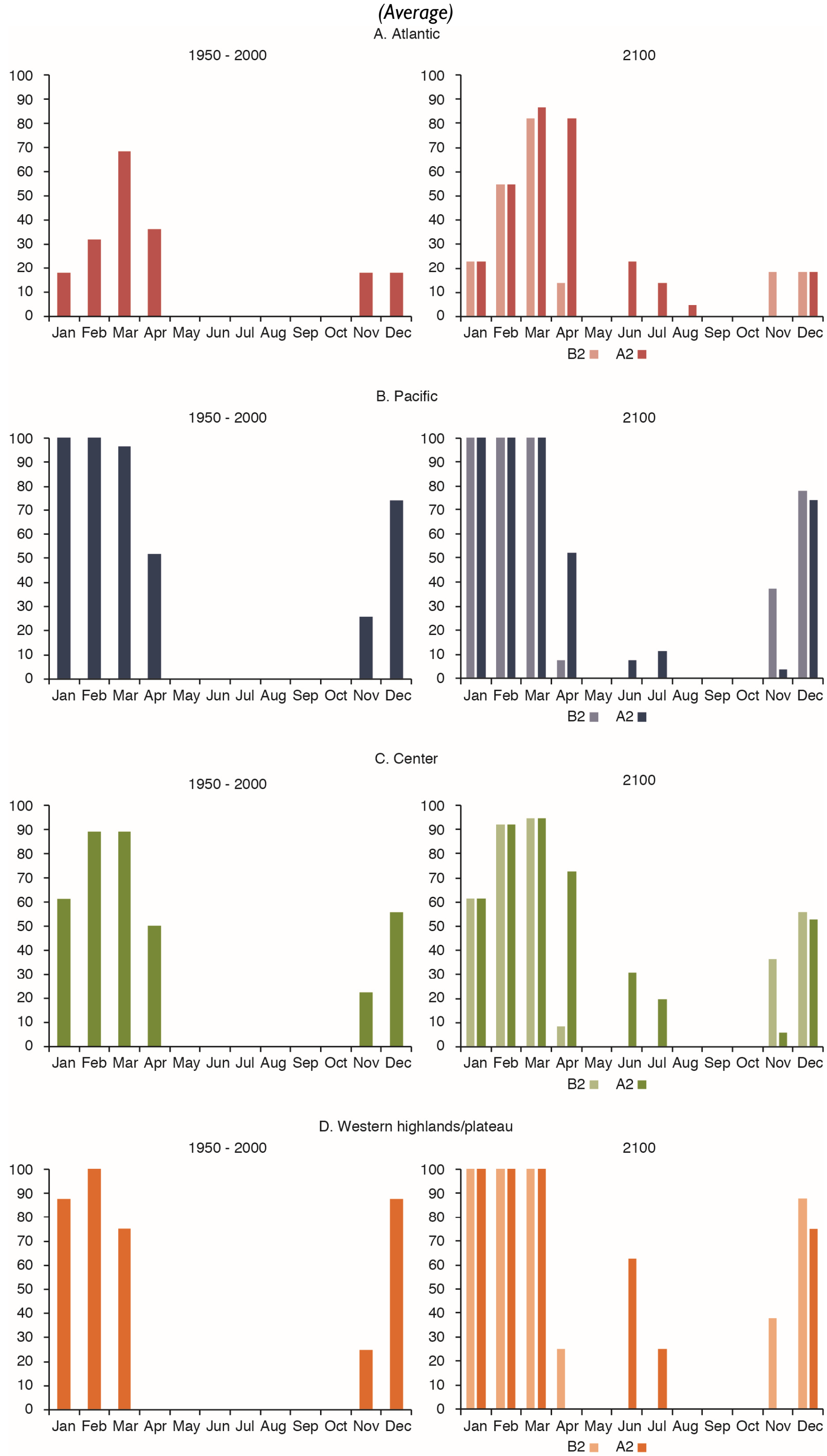
Guatemala, El Salvador, Honduras and Nicaragua as of 2070. It is expected that the departments of Zacapa, Chiquimula, El Progreso and Jalapa in the Guatemalan dry corridor, the departments of Choluteca, El Paraíso and Francisco Morazán in Honduras, and León and Estelí in Nicaragua will have dry seasons lasting seven months, contrasting with the historical pattern of 6 months for the departments in Guatemala, and five months for those in Honduras and Nicaragua.

With regard to intra-annual dry month patterns, it is estimated that under scenario B2 the onset and the end of the rainy season would take place earlier in the year. Under scenario A2, the onset and the end of the rainy season would take place later. Changes in the intra-annual dry month pattern would be more pronounced in Guatemala, Honduras and Nicaragua, due to the possible occurrence of dry months in parts of their territory in June, July and August under scenario A2. The period of "dog days" usually occurs during these months, but, historically, humidity has not been low enough for this period to be defined as dry months. These changes could be significant due to their impact on agricultural cycles and operating rules for hydroelectric plants. Figure 19 illustrates the estimated pattern for the dry season up to 2100 under scenarios B2 and A2 in the geoclimatic regions identified previously, and compares it to the average pattern for the period 1950-2000. It is estimated that in the Atlantic region, under scenario B2, there will be an increase in the number of departments experiencing dry month conditions during February and March, and a decrease in April. Under scenario A2, it is expected that there will be an increase in the number of departments with dry month characteristics during March and a slight decrease with respect to B2 in April, while, by 2100, no department will have dry month characteristics in November.

To summarize, this study demonstrates that the two scenarios for climate change lead to different impacts on aridity and dry months at the country, department and geoclimatic region levels. Nevertheless, if global emissions continue their current upward trend, the more pessimistic scenario (A2) will be the most probable. Given the variability of conditions and the cumulative trend of aridity predicted for the upcoming decades, Central American societies needs to become bold managers of water resources, ensuring their sustainable and efficient use for the benefit of the population and production. Even without climate change, the demand for water will increase significantly in the region. With climate change, is it estimated that there will be a decrease in humidity and the overall availability of renewable water, particularly for the five countries north of Costa Rica.

Scenarios of aridity and dry months evince the urgency of safeguarding food security, particularly when it comes to basic grain supplies, and of making the transition to more sustainable agriculture. This is a significant challenge, but addressing it is necessary in order to protect the poor, both small-scale producers and urban consumers. The estimated changes in aridity will have implications on the viability of ecosystems in the region and the impact of extreme events such as fires. These ecosystems depend on relatively humid climates, though not without variation (i.e. there are different types of humid and dry tropical forests). Protecting and restoring these ecosystems is a significant development challenge even without accounting for climate change. Information that is georeferenced and disaggregated by department and geoclimatic region, and divided temporally by cut-off years and intra-annual patterns is a useful tool to refine the analysis of potential impacts on different sectors. It is important to highlight that the region would have better access to the required knowledge if it were to expand and strengthen its network of meteorological and hydro-meteorological stations as well as its network of climatology and hydrology professionals.

FIGURE 19
CENTRAL AMERICA: AVERAGE NUMBER OF DEPARTMENTS WITH DRY MONTHS BY GEOCLIMATIC REGION, 1950-2000 AND SCENARIOS B2 AND A2 UP TO 2100
(Average)



Source: Prepared by the authors.

4. POTENTIAL IMPACTS ON HYDROELECTRIC POWER GENERATION

Within the framework of this initiative, a study of the potential impacts of climate change on hydroelectric power generation was carried out using the climate change scenarios developed for the initiative (ECLAC, CEL, MARN, COSEFIN, CCAD/SICA, UKAID & DANIDA, 2012). Energy production was studied at two hydroelectric power plants selected by their respective authorities: Cerrón Grande in El Salvador, which uses water from the Lempa river, and Chixoy in Guatemala, which uses water from the Chixoy river. This study is part of a technical series that uses analyses prepared by various teams of experts coordinated by ECLAC and reviewed and approved by the Regional Technical Committee (RTC) of the ECCCA with the help of regional experts.

Information for the simulations of both watersheds was provided by the National Electrification Institute of Guatemala (INDE) and the Hydroelectric Executive Commission (CEL) of Río Lempa. For the simulations, flow in each basin was estimated taking hydrological balance into account. The simulations used the Water and Power Potential programme (WAPPO), which is based on the main parameters of the hydrological cycle and which integrates meteorological, geomorphological and hydrological information. Hydrological balance expresses the relationships between the decisive parameters of the hydrological cycle and their variations. As shown by the results, precipitation is the determining factor when it comes to the effects of climate change on availability of water. Temperature increases evapotranspiration in the basin, but tends to produce minor changes in hydrological balance.

For the purposes of this study on hydroelectric power generation, calculations were made using the average of the results for three general circulation models for each IPCC scenario: HADCM3, GFDL R30 and ECHAM4 for B2, and HADGEM1, GFDL, CM2.0 and ECHAM for A2. Changes in precipitation and temperature were calculated for the cut-off years 2020, 2030, 2050, 2070 and 2100 using the average of the values of these anomalies for the departments that are part of the river basins. Since the analysis involves long-term scenarios with various "layers" of analysis and methodological difficulties and uncertainties, the results should be interpreted as trends and relative magnitudes, rather than exact predictions and figures.

Figures 20 and 21 and Tables 4, 5, 6 and 7 (available at the end of this chapter) summarize the results of the hydrological simulations and reservoir operation simulations for scenarios B2 (less pessimistic) and A2 (more pessimistic). The first column in the tables indicates the time period considered, the second describes the climate change scenario, the third indicates the hydrological balance of the basins, the fourth shows the results of the reservoir evaporation analysis and the percentage increase for each climate change scenario, the fifth shows the water flow corresponding to each scenario and the percentage difference relative to current values, and the sixth indicates the amount of energy generated and the percentage difference relative to current values.

It is estimated that under scenario A2, the temperature of the Chixoy river basin would gradually increase by 4.9°C by 2100, while precipitation would gradually decrease by approximately 30% with respect to the 1961-1990 average. The rate of decrease would accelerate in the second half of the century. This would result in a greater proportion of rain being lost to evapotranspiration, reaching more than 90% by 2100. However, the total volume of evapotranspiration would decrease by 12%, including direct evaporation and vegetation transpiration. Under scenario B2, temperatures would gradually rise during this period of time, increasing by approximately 3.0°C by 2100. Precipitation would surpass the historical average by 4.6% and 4.0%, by 2020 and 2030 respectively. Precipitation would continue to decrease over time, and by 2100 precipitation would be an estimated 0.1% lower than the historical average. It is estimated that under scenario B2 there would be an increase in the percentage of precipitation lost to evapotranspiration, reaching more than 80% in 2100. In this situation, the total volume of evapotranspiration would have increased by 10%.

It is estimated that under scenario A2 the temperature of the Lempa river basin would increase by 4.8°C by 2100, while precipitation would gradually diminish, reaching a value 30% lower than the 1961-1990 historical average by 2100; a third of this decrease would take place between 2070 and 2100. As a result, it is estimated that the percentage of rain lost to evapotranspiration would increase, reaching 88% by 2100, while the total volume of evapotranspiration would decrease by 17% by 2100. Under scenario B2, the temperature increase would be 3°C, and, until 2070, precipitation would be approximately 4% greater than its historical value. It is estimated that by 2100, precipitation will be 2% lower than the historical value. This scenario estimates an increase in the percentage of precipitation lost to evapotranspiration, reaching 77% by the end of the century; however, total volume of evapotranspiration would remain relatively stable.

The closeness of the link between evapotranspiration and precipitation is largely attributable to a decrease in rainfall, which results in significant water loss due to evaporation, transpiration, infiltration, etc. It is possible to conclude that precipitation is the parameter that largely determines the availability of water in both basins and that there will be an increase in the proportion of rain lost to evapotranspiration. It is likely that this phenomenon is already happening, and that there will be an increase in demand for water for other uses, and, therefore, lower water flow for power generation.

The hydrological simulation model assumes a stationary state for both basins. For future studies, it is recommended that more sophisticated models that integrate other parameters such as land use and population levels be used. These models require specialized training and disaggregated data, which is not always available.

The simulations also assume average water-distribution conditions. However, the reality is that in dry or humid years, water distribution can be very different from average distribution. During dry years, the period of low water levels can be very long and severe, while in humid years the rainy season can be very intense at certain times, for example, during tropical cyclones. These conditions affect water availability and must be studied in greater depth.

Before carrying out a simulation using a hydrological model that integrates other parameters, it is important to note that land-use changes might not significantly alter water availability, though they might affect its distribution. Vegetation (including forests) consumes water, but at the same time it regulates water flow in river basins and protects the soil. It is likely that using forest floors for

agricultural and livestock use—the trend in Central America—will have a more pronounced impact on basin erosion than on water availability. Likewise, population growth impacts quality of water more than the quantity, except when significant quantities are transported to cities.

The results of the reservoir operation simulation under the conditions of the climate change scenarios indicate that water flow will increase or decrease in proportion with precipitation if the differences between current and future precipitation levels are not very large. However, it must be noted that losses to evapotranspiration will increase due to temperature increases.

According to the simulations of the river basins in the climate change scenarios, water flow in the Chixoy reservoir would gradually decrease by up to 83% in 2100 in the more pessimistic scenario (A2). Water flow in the Cerrón Grande reservoir would decrease in the long term by as much as 70%, with notable inter-annual variations. Under scenario B2, the effects on Chixoy would be related more to the increase in temperature than to the decrease in precipitation. By the end of the century, precipitation levels would not be very different from those in the historical reference period; however, a 3°C temperature increase would mean a 28% water flow reduction for that same year. In Cerrón Grande, a 2% decrease in precipitation and a 3°C increase in temperature could reduce water flow by 15%.

The simulations are based on average water distribution, but availability of water could be lower than estimated because distribution tends to vary significantly, particularly during dry years. Run-of-river hydroelectric power plants and daily regulation reservoirs were not considered in this study, but they would obviously be greatly affected if water flow were to decrease due to a lack of storage capacity during rainy seasons. Basin deterioration and decreased storage capacity due to sedimentation of the reservoirs affect current availability of water and would do so with more severity in the future. These elements have not been taken into account in this study, but their effects will be very important and should be estimated.

According to the climate-change scenarios, reservoir losses due to evaporation would increase throughout the century, mainly due to a gradual increase in temperature. Under the more pessimistic scenario (A2), evaporation of the Chixoy reservoir would increase gradually, up to 41% (from 0.33 m^3/s to 0.47 m^3/s) by 2070. However, by 2100 the rate would decrease to 0.40 m^3/s, due to a decrease in the amount of water entering the reservoir. Under scenario B2, evaporation would gradually increase, especially after 2050, reaching a maximum rate of 0.47 m^3/s towards 2100. In Cerrón Grande, evaporation loss is already much higher than in Chixoy, and it would continue to gradually increase over time, especially after 2050. Under scenario A2, it is expected that evaporation losses will reach a maximum value of 4.97 m^3/s by 2100, i.e. a 22% increase relative to the historical reference value. In the less pessimistic scenario (B2), evaporation loss would be smaller, increasing by up to 8% with a maximum value of 4.93 m^3/s in 2100. In absolute terms, additional evaporation losses would be higher for the Cerrón Grande reservoir (0.9 m^3/s in A2 and 0.32 m^3/s under B2), than for Chixoy (0.14 m^3/s in both scenarios).

Power generation at both plants is highly dependent on water flow. When flow decreases at the Chixoy reservoir, the amount of energy produced decreases almost in the same proportion, but when flow increases, the plant does not see a proportionally equivalent increase in energy. At the Cerrón Grande reservoir, small increases or decreases in the average annual flow translate into proportional increases or decreases in the amount of power generated. At Chixoy, large increases in

flow yield small increases in power generated. This difference is due to the fact that Cerrón Grande is able to use almost all of the water available to generate power; however, large decreases in average annual flow translate into proportional decreases in power output for both plants.

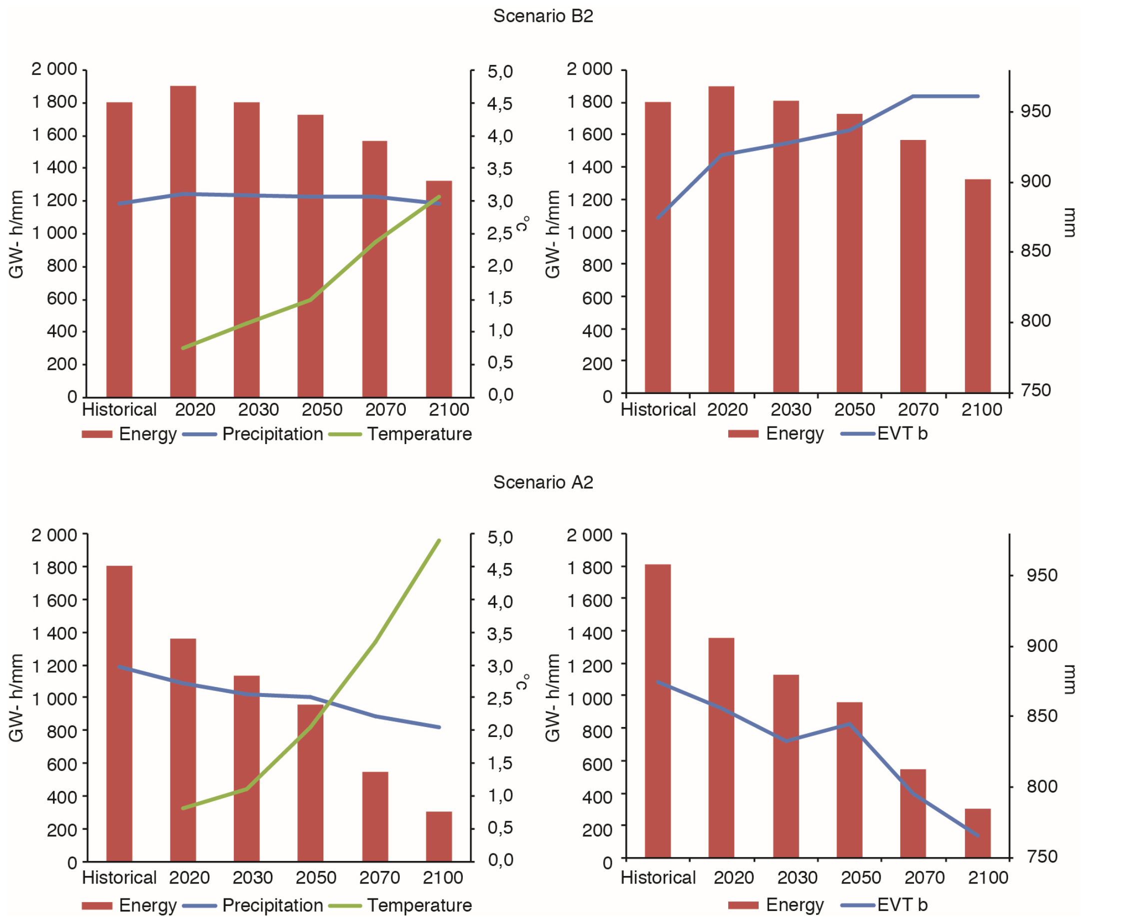
Estimates of power generated vary according to the scenarios and the cut-off year (2020, 2030, 2050, 2070 or 2100). It is estimated that in the more pessimistic scenario (A2), there will be decreases of over 20% in both plants by 2020 relative to the average power output for the reference period (1979-2008 for Chixoy and 1984-2009 for Cerrón Grande). After 2050, decreases will be greater than 40% in both plants. Under scenario A2, it is expected that Chixoy will see decreases of 25% by 2020, 37% by 2030, 47% by 2050, 70% by 2070 and 83% by 2100. Under the same scenario, it is expected that Cerrón Grande will experience decreases of 22% by 2020, 34% by 2030, 41% by 2050, 57% by 2070 and 71% by 2100. In the less pessimistic scenario (B2), by contrast, it is expected that there will be an increase of 4% to 6% in both plants by 2020 relative to the reference period. After 2020, the estimates become negative, reaching a decrease of 26% in Chixoy and 17% in Cerrón Grande by 2100.

Maximum power generation occurs in the months when water flow entering the reservoirs is greater than water flow entering the turbines. For both reservoirs, the filling period lasts five months (from June to October), associated with the rainy season. This pattern would change for Cerrón Grande given the extreme drought conditions estimated by both scenarios for the end of the century. Under these conditions, filling of the reservoir would be prioritized over power generation during the rainy season, meaning that the plants would generate the most power during the emptying stage.

The decrease in flow (and therefore in power generation) caused by increases in temperature would not be significant on an annual basis, but could be problematic during periods of low water levels. This decrease would take place in all types of hydroelectric plants, but the negative effects would be more severe in run-of-river and daily regulation reservoirs, which are unable to regulate when water is abundant. A decrease in production of firm energy at the plants might also be seen. This might already be happening, but the effects are not noticeable as the current period is a humid one, as indicated by time series.

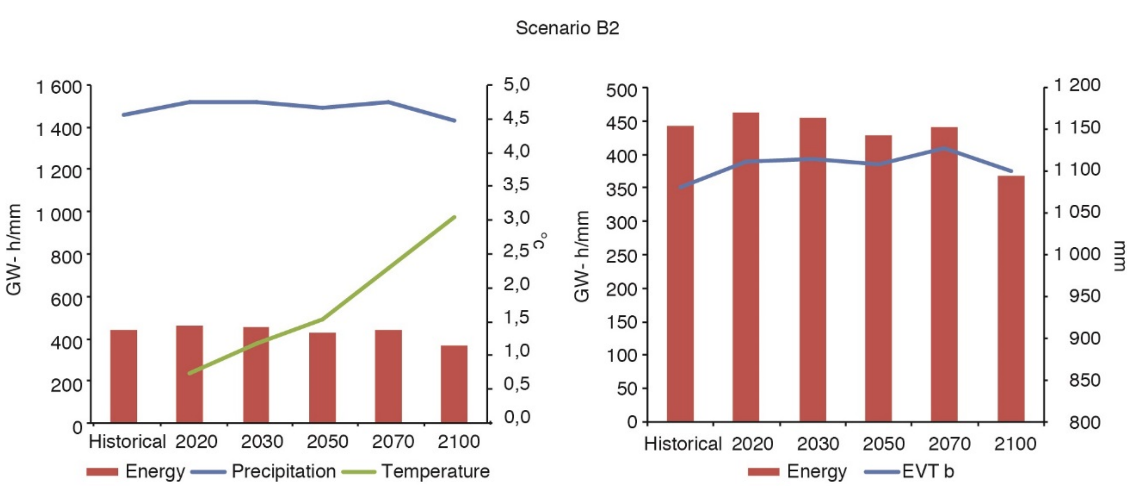
Figures 20 and 21 summarize the results and illustrate the relationship between climate variables and power generation. In the more pessimistic scenario (A2), the greatest temperature increase and the lowest amount of precipitation gives rise to a decrease in evapotranspiration, unlike with the less pessimistic scenario (B2). Under scenario A2, extreme changes in temperature and precipitation result in less evapotranspiration in the river basins and decreased water flow for power generation in both plants. Under scenario B2, it is expected that Chixoy will see relative stability in precipitation, temperature increase and evapotranspiration, which will result in a lower water flow for power generation. Cerrón Grande would experience relatively stable evapotranspiration and power generation.

FIGURE 20
CHIXOY POWER PLANT: SIMULATION RESULTS, 2020-2100



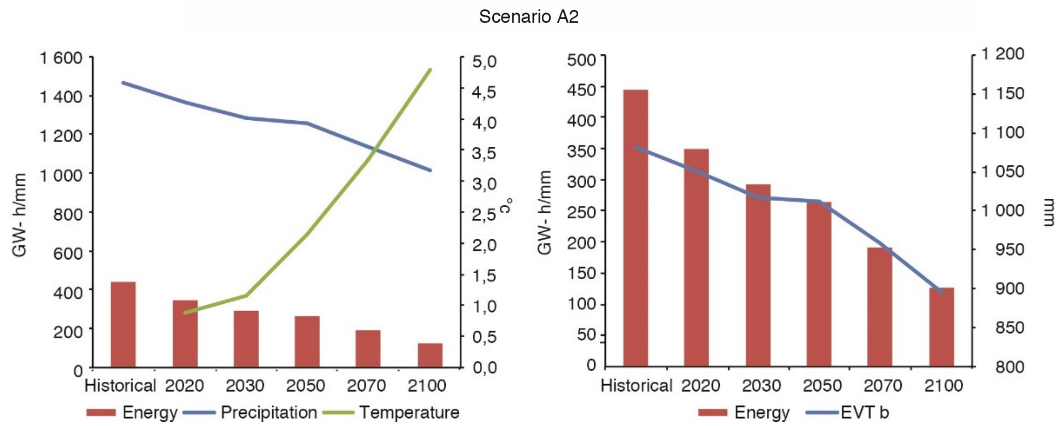
Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008. EVT = Evapotranspiration. Energy and precipitation are on the left axis, EVT and temperature are on the right axis.

FIGURE 21
CERRÓN GRANDE POWER PLANT: SIMULATIONS, 2020-2100



(Continued)

(Conclusion)



Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008. EVT = Evapotranspiration. Energy and precipitation are on the left axis, EVT and temperature are on the right axis.

Power generation will gradually decrease due to a loss of water-storage capacity caused by reservoir sedimentation, a critical factor that should be considered when making future energy generation plans.

To summarize, the expected gradual increase in temperature (greater in A2 than in B2) will affect hydroelectric power generation due to increased evapotranspiration in the river basin and increased evaporation in the reservoirs. It is important to note that the increase in atmospheric temperature could contribute to more intense rainfall events, while the increase in sea surface temperature could give rise to more intense hurricanes. Nevertheless, the greatest risks are related to rain, whose pattern in the region already shows great variability in its annual accumulation and intra-annual distribution. Future scenarios suggest a possible increase in the variability of annual accumulated rainfall, with a gradual reduction in the annual average, especially in the second half of the century. That being said, rainfall modelling involves several unknowns that still need to be identified. The current and future scenarios indicate the existence of a short-term window of opportunity which will close if it is not used to strengthen the management of basins, reservoirs and existing plants, and create new initiatives for comprehensive water management and adaptation to climate change. A summary of the recommendations resulting from this study is presented below.

Currently, maximum power generation occurs in months when the flow of water entering the reservoir is greater than the flow through the turbine. The filling period in both plants lasts approximately five months, from June to October. This pattern would change for both plants under scenario A2, which estimates a general decrease in precipitation. Under scenario B2, the pattern would change only for Cerrón Grande in the last few years of the century. This estimate is based on the assumption that operating rules prioritize filling of the reservoir over power generation during the rainy season. The plants would therefore generate more power during the emptying stage of the reservoir, between November and May, although the total annual output would be lower.

Power generation would gradually decrease due to a decrease in reservoir storage capacity due to sedimentation, a critical factor to consider in plans for future power generation. It is recommended that this factor be studied in order to calculate loss of generation capacity, and to

create alternative generation plans or reservoir recovery plans that include recovering forests in river basins and other measures for comprehensive river basin management.

In order to adapt to changing conditions, it is essential to have all the information needed to make decisions. The information used for this study shows that the authorities are invested in appropriate operating planning for the plants. However, some aspects of the hydro-meteorological information available can be improved. There are two factors important to the measurement of precipitation: the number of stations and their locations. It is recommended that meteorological station coverage be improved in the river basins in order to meet the minimum number recommended by the World Meteorological Organization (WMO). Currently, there are very few stations in the river basin areas, which makes it difficult to identify rain variation patterns along relatively large river basins. Furthermore, most of the stations are located in the lower areas of the basins, which makes it difficult to identify rain patterns at higher altitudes and thus complete water balance calculations for the basin.

With regards to Cerrón Grande, it would be very useful to have information on tank evaporation from sites close to the reservoir. Including evaporation as a parameter when calculating balance would provide information that could help reduce this type of loss in reservoir operation.

This study has evaluated the effects of climate change based on the moving averages of temperature and precipitation changes, where the values estimated for cut-off years correspond to the average values for ten-year periods. In the short term, it is recommended that a historical analysis of climate variability, as well as estimates for precipitation scenarios over the next two decades, be carried out, in order to predict possible changes in variability between dryer and more humid years.

In order to improve water balance results, it is recommended that models that include land use and population growth be used in the short term, taking into account their probable effects and the resources needed to address them. Similarly, it is also recommended that the effect of increasing temperatures on power generation in dry periods be analyzed. Such effects might already be present, and therefore require attention in order to devise urgent adaptation measures.

Analyses of operations should also consider the role of future reservoir projects with regard to adaptation to climate change, taking into account routine operations of both the reservoir and the plant, and emergency measures in case of excess or lack of water flow. Analyses should consider not only the plants, but also the management of each river basin.

It is recommended that the efficiency of all systems that use water be improved to prepare for eventual decreased availability and that river basins be managed properly to prevent soil erosion and reservoir sedimentation. In order to do this, initiatives relating to forest conservation, reforestation, appropriate land use and irrigation are needed.

With regards to available water flow, it is recommended that the operation of water-management systems, including those in hydroelectric plants, be optimized. In the same vein, it is recommended that seasonal water-storage systems be implemented to compensate for the decrease in water flow during periods of low water levels.

It is recommended that evaporation parameters be included in the calculation of reservoir balance. The results of the simulations suggest that proper reservoir operation could reduce this type of loss, and, therefore, further research is recommended.

To increase power generation in both basins, it is recommended that operating models of the plant reservoirs be reviewed in order to optimize power generation in the face of scenarios of reduced water flow and probable increases in water flow variability in the short term. The silting processes of the reservoirs should be studied in order to quantify the decrease in plant generation capacity, and to devise alternative energy production plans and restore reservoirs.

It is recommended that this analysis be applied to other hydroelectric plants in the region, particularly to those of strategic importance. It will be important to study the effect of the climate change scenarios on run-of-river and daily regulation reservoirs, and especially the effect on power generation during periods of low water levels.

Future research should discuss the adaptation of future reservoirs projects to climate change, as is the case with El Tigre (binational with Honduras) on the Lempa River and upstream projects (Serchil) in the Chixoy river basin. In order to ensure sufficient water supply for power generation and other activities related to water resources, it is recommended that seasonal regulation reservoirs (at the least) be built.

It must be remembered that Chixoy is a tributary of Usamacinta (binational with Mexico), which does not have reservoir infrastructure. The Usumacinta-Grijalva flows into Villa Hermosa, Tabasco, Mexico, which has been greatly affected by floods and is threatened by a possible rise in sea level.

TABLE 4
CHIXOY PLANT: RESULTS OF SIMULATIONS, SCENARIO B2, 2020-2100
(Percentages, degrees centigrade, mm, cubic metre per second, gigawatt-hour)

Year	CC Scenarios		Balance			Evaporation			Flow		Energy	
	P (%)	T (°C)	P (mm)	EVT (mm)	EVT/P (%)	(mm)	(m^3/s)	(%)	(m^3/s)	(%)	(GW-h)	(%)
Reference			1186	875	74	97.3	0.33		54.99		1805	
2020	5	0.77	1241	919	74	102.8	0.41	24	57.00	4	1899	5
2030	4	1.14	1234	928	75	105.5	0.42	27	54.18	-1	1806	0
2050	4	1.50	1230	937	76	108.2	0.43	30	51.79	-6	1727	-4
2070	3	2.37	1226	961	78	114.8	0.45	37	46.92	-15	1565	-13
2100	0	3.06	1186	961	81	120.2	0.47	42	39.79	-28	1328	-26

Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008; P = precipitation, T = temperature, EVT = evapotranspiration, EVT/P = the fraction of precipitation that becomes evapotranspiration.

TABLE 5
CERRÓN GRANDE PLANT: RESULTS OF SIMULATIONS, SCENARIO B2, 2020-2100
(Percentages, degrees centigrade, mm, cubic metre per second, gigawatt-hour)

Year	CC Scenarios		Balance			Evaporation			Flow		Energy	
	P (%)	T (°C)	P (mm)	EVT (mm)	EVT/P (%)	(mm)	(m^3/s)	(%)	(m^3/s)	(%)	(GW-h)	(%)
Reference			1460	1081	74	119.1	4.07		107.90		443	
2020	4	0.74	1519	1111	73	121.3	4.13	2	112.88	5	463	4
2030	4	1.17	1517	1115	74	122.8	4.19	3	111.39	3	456	3
2050	2	1.53	1488	1108	74	124.2	4.24	4	105.37	-2	429	-3
2070	4	2.29	1518	1128	74	127.8	4.36	7	108.05	0	441	-1
2100	-2	3.04	1431	1100	77	132.5	4.39	8	91.58	-15	369	-17

Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008; P = precipitation, T = temperature, EVT = evapotranspiration, EVT/P = the fraction of precipitation that becomes evapotranspiration.

TABLE 6
CHIXOY PLANT: RESULTS OF SIMULATIONS, SCENARIO A2, 2020-2100
(Percentages, degrees centigrade, mm, cubic metre per second, gigawatt-hour)

Year	CC Scenarios		Balance			Evaporation			Flow		Energy	
	P (%)	T (°C)	P (mm)	EVT (mm)	EVT/P (%)	(mm)	(m^3/s)	(%)	(m^3/s)	(%)	(GW-h)	(%)
Reference			1186	875	74	97.3	0.33		54.99		1805	
2020	-8	0.81	1086	856	79	103.1	0.40	22	40.70	-26	1359	-25
2030	-14	1.10	1024	833	81	105.2	0.41	24	33.82	-39	1130	-37
2050	-15	2.05	1007	845	84	112.4	0.43	32	28.76	-48	961	-47
2070	-25	3.34	889	796	90	122.4	0.47	41	16.39	-70	544	-70
2100	-31	4.89	818	766	94	135.0	0.40	22	9.22	-83	305	-83

Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008; P = precipitation, T = temperature, EVT = evapotranspiration, EVT/P = the fraction of precipitation that becomes evapotranspiration.

TABLE 7
CERRÓN GRANDE PLANT: RESULTS OF SIMULATIONS, SCENARIO A2, 2020 A 2100
(Percentages, degrees centigrade, mm, cubic metre per second, gigawatt-hour)

Year	CC Scenarios		Balance			Evaporation			Flow		Energy	
	P (%)	T (°C)	P (mm)	EVT (mm)	EVT/P (%)	(mm)	(m^3/s)	(%)	(m^3/s)	(%)	(GW-h)	(%)
Reference			1460	1081	74	119.1	4.07		107.90		443	
2020	-7	0.89	1364	1051	77	121.8	4.19	3	86.55	-20	348	-22
2030	-12	1.16	1282	1017	79	122.8	4.24	4	73.30	-32	291	-34
2050	-14	2.15	1253	1012	81	127.1	4.40	8	66.85	-38	263	-41
2070	-22	3.33	1135	959	84	135.2	4.63	14	48.75	-55	191	-57
2100	-31	4.78	1014	896	88	164.7	4.97	22	32.76	-70	126	-71

Source: Prepared by the authors.
Note: Historical reference period, average 1979-2008; P = precipitation, T = temperature, EVT = evapotranspiration, EVT/P = the fraction of precipitation that becomes evapotranspiration.

5. POTENTIAL IMPACTS ON ECOSYSTEMS

Central America has a great diversity of ecosystems, including its tropical forests. In 2005, tropical forests covered about 45% of the territory of the region and were home to approximately 7% of the planet's biodiversity (ECLAC/CCAD/SICA/UKAID/DANIDA, 2011a; INBio, 2004). Tropical forests are extremely rich in terms of biodiversity and biomass because the energy from the sun at the equator allows life to thrive amidst abundant nutrients. Each part of the forest contributes to sustaining life. The earth is populated by huge numbers of microbes, insects and fungi that are essential for the recycling of organic matter and species survival. Ecosystems play a role in climate regulation since they help to maintain the gaseous composition of the atmosphere (Salzman, 1998). Forests are carbon sinks that capture atmospheric CO_2 and thereby mitigate the greenhouse gas (GHG) effect worldwide. Ecosystems directly regulate local and regional climate through their role in the water cycle. Water absorbed by plants through their roots evaporates through their leaves, and therefore, air temperature and humidity levels can change if climate change affects this contribution from ecosystems.

Central America depends on its forests, as they are an invaluable resource that provides multiple products and services, partly compensate for the low-income population's limited access to the market and provide shelter against natural disasters such as floods and tidal waves. In many areas, there is a very close relationship between the indigenous people and the forests, not only in terms of productive activities, but also in terms of identity, culture and history.

Unfortunately, these forests are very fragile. The available data shows that the influence of human activities on ecosystems is significant and modifies their availability, structure and systemic behavior (Millennium Ecosystem Assessment, 2005). Along with plants and animal reserves, the world's forests are threatened as never before. It is estimated that between 2000 and 2010, 13 million hectares of forest were converted every year for other uses or were lost due to natural causes (FAO, 2010). Not all of the affected forests have disappeared entirely. Many of them have been partitioned by highways and human development; these changes threaten the health and survival of native plants and animals. Currently, there is a large number of endangered species and ecosystems, and their ability to recover naturally without human help no longer seems a viable option, given that their resilience has weakened notably in the last few decades (IPCC, 2007c). Moreover, the majority of climate change impacts tend to intensify downward trends (IPCC, 2007c; Parmesan & Yohe, 2003), which makes it difficult to identify and isolate the specific effects of climate change on ecosystems; this suggests that climate change impacts could be having a greater-than-proportional effect when combined with other negative factors.

In Central America, even without climate change, these pressures will probably continue to intensify, at least until the human population stabilizes around 2070 and until the economy transitions to a model that uses natural resources more efficiently and with less pollution. The increase in extreme events recorded in the last few decades—especially hydro-meteorological events

such as droughts, hurricanes and floods—often aggravates the destruction of ecosystems in the affected areas. For instance, hurricane Felix affected an extensive area of forest in Nicaragua's North Atlantic Autonomous Region in 2007 (ECLAC/CCAD/SICA/UKAID/DANIDA, 2011a).

In this context, climate change emerges as a significant added risk since it increases temperature levels and modifies precipitation patterns, and will likely decrease the volume of rainfall in the medium term. It is also likely that humidity levels will diminish and that the rising temperature of the sea surface will increase the destruction caused by hurricanes and tropical storms.

Specialized literature has identified the following possible impacts of climate change on natural ecosystems: changes in evaporation patterns, changes to cloud cover at vegetation level, perturbations to mountain ecosystems, decreases in tropical and montane area and an increase in pre-montane area, and the appearance of tropical very dry forest and dry premontane forest. Habitat loss could also occur due a greater frequency of forest fires, droughts, floods and changes in the soil sediment in low lands; as a result, invasive species and new disease vectors could proliferate.

A different approach to analysis seeks to evaluate the direct impact of climate change on biodiversity. Of the studies carried out, three analyze the entire region using different methods. The study titled "Potential Impacts of Climate Change on the Biodiversity of Central America, Mexico and the Dominican Republic" (CATHALAC & USAID, 2008), carries out a geo-referenced analysis of the richness of species in the regions. For the climatic analysis, the study uses climatological data and high-resolution scenarios from SERVIR, PRECIS and WorldClim with three models and scenarios B2 and A2. Using this data, a Climate-Change Severity Index (CCSI) was formulated; this index measures the displacement of species away from their natural comfort zones. According to this analysis, under scenario A2, the Caribbean coast, from Honduras to Panama and the Dominican Republic, rich in biodiversity, will be severely affected by climate change in the 2020s. In the 2080s, all of the ecosystems and species of Central America and the Dominican Republic could be displaced from their natural comfort zones.

The study titled, "Current and Future State of Biodiversity in Central America" (PROMEBIO, 2010) was drafted by CCAD's Strategic Program for Monitoring and Assessment of Biodiversity, located at Zamorano Pan-American Agricultural School. The modelling for this study is based on GLOBIO3 methodology (Global Biodiversity Model), developed by the Netherlands Environmental Assessment Agency and UNEP. It accounts for factors relating to human pressure on biodiversity: land use, infrastructure, fragmentation of natural areas, climate change and nitrogen deposition. The analysis allows for the creation of the Mean Species Abundance (MSA) index, which measures abundance relative to original abundance. The index indicates a 52% loss and a 48% relative abundance. The contribution of climate change to biodiversity loss is 2.5%, while land use is responsible for 34%. According to projections for 2030 for three development scenarios, the MSA will decrease by between 41% and 43%. In all three cases, climate change's contribution will increase by approximately 4%.

The studies based on species records have to estimate the total number of existing species, since not all species have been identified. While previous studies used the richness method for species in Central America, the ECCCA initiative opted for a different approach. This study on biodiversity and climate change (ECLAC, CCAD/SICA, UKAID/ DANIDA, 2011b) uses the Biodiversity Potential Index (BPI), which combines climate and territory variables and indicates how

likely it is to find a high amount of biodiversity in a given area. The variables considered are: total surface area, surfaces with non-urban and non-agricultural ecosystems, latitude, level curves, temperature, precipitation and availability of water. Areas with the greatest number of level curves are more likely to have a greater number of ecosystems than areas with fewer level curves. At higher temperatures, there is greater biological activity, as can be seen in the great biodiversity and concentration of forests along the equator. The temperature and precipitation projections resulting from the general circulation models HADCM3 and HADGEM1 for scenarios B2 and A2 respectively show that BPI will decrease significantly in all countries, with the decrease being larger under scenario A2. At the regional level, the simulation estimates a reduction in index value of more than 13% for land-use change (LUC) only, compared to a loss of 18% for LUC and B2 and 36% for LUC and A2 by 2050. By 2100, the decrease will reach 33% and 58% for the two climate change scenarios. The estimated decrease in biodiversity potential by 2100 under scenario B2 ranges from 22% in Belize to 50% in Nicaragua. Under scenario A2, the decreases lie between 70% and 75% for Guatemala, Nicaragua, El Salvador and Honduras, and between 38% and 43% for the other three countries.

Potential impacts on ecosystems would not only result from climate change, but also from the reaction of the human population to it. For instance, if yields of basic grains and other products decrease, the pressure to increase the area of agricultural land at the expense of forests would increase. Therefore, the measures taken by economic stakeholders should aim to reduce such pressures and to facilitate adaptation of the ecosystems to climate change; however, this will not happen in the absence of public policies, economic incentives, and multisectoral agreements oriented towards sustainability. In international climate change negotiations, forests are at the center of various technical and political debates, not only because of deforestation and degradation, their relation to greenhouse gas (GHG) emissions and their function as carbon sinks, but also because of their importance to the lives and culture of rural populations and indigenous communities, and to the efforts to improve the sustainability of economic activities, such as agriculture and the sustainability of hydroelectric power generation. For this reason, it is important to make progress in the analysis of the impact of climate change on forests, their adaptation needs and their vital role in the adaptation of societies.

Besides the threats of deforestation, degradation and climate change, the efforts to protect forests face an additional challenge: the unquestionable economic value of forests as providers of goods and services to society is not reflected in market prices or, often, anywhere at all. When an economic actor destroys or contaminates an ecosystem, a negative externality is created and is not accounted for as an economic loss. Given this situation, it cannot be expected that these services will be incorporated into the market in time to incentivize appropriate decisions regarding use and conservation. Market signals for agricultural productivity, availability of water and other factors will appear only when the assets have been depleted, which would happen even without climate change.

In recent decades, considerable efforts have been made to improve our understanding of the contribution that ecosystems provide and of how to estimate their economic value. Several countries in the region have established payment systems for environmental services, and there are now more than 550 Natural Protected Areas. Important studies on the risks of climate change, especially for forests and biodiversity, have also been carried out. Progress been made with methods to estimate environmental losses due to extreme events. These costs have been estimated in 14 assessments of major events in Central America in recent decades. In 2011, the Ministers of Environment agreed to improve the methodology of these assessments.

It is also important to assess ecosystems using non-market criteria, taking into account the related scientific knowledge and cultural values. This type of assessment helps to incentivize the development of precautionary measures given that the market does not send the right signals. Economic assessment analyses are useful, but have limitations because it is not always easy to assign a monetary value to certain services, especially invaluable intrinsic values, like those related to regulation, existence and culture. The challenge of developing an appropriate way of broadly evaluating ecosystems is increasingly urgent due to the threat of climate change.

In the context of these three challenges, this study's objective is to develop scenarios of the potential geographic distribution of forest ecosystems in Central America in the future (ECLAC, COSEFIN, CCAD/SICA, UKAID & DANIDA, 2012c). The study estimates the loss in area available to these ecosystems caused by human pressure without climate change, using a land-use change scenario for 2100 prepared by the Tropical Agricultural Research and Training Centre (CATIE) at the request of "The Economics of Climate Change in Central America" initiative (ECLAC, CCAD/SICA, UKAID & DANIDA, 2011a). This scenario estimates that the area of land dedicated to agricultural activities would increase by about 30% during this century, thereby reducing the area of forests and pastures, and savannah and bushland by 33% and 83% respectively. These changes would mainly take place in the next four decades.

The study starts by representing the region's ecosystems using the Holdridge Life Zones (HLZ) method. HLZs are considered to be those areas that have "adequate climate conditions for a given ecosystem" (Holdridge, 1947; Locatelli & Imbach, 2010). An HLZ is a group of vegetal associations within a natural climate division, according to edaphic conditions and succession stages, with similar physiognomy in all parts of the world. These associations define a series of environmental conditions which, together with other living beings, form a unique combination of vegetal physiognomy and animal activity. The HLZ classification provides a logical basis for defining local ecosystems in a comparable framework. To specify climate conditions for the base year (2005), average monthly precipitation and temperature data were obtained from WorldClim for the period 1950-2000 (Hijmans and others, 2005). Thus, it was determined that in 2005 Central America had approximately 28.5 million hectares of natural cover. In a scenario involving land-use change without climate change, it is estimated that this area would decrease by approximately 11.5 million hectares by the end of century, first decreasing to close to 16.3 million hectares by 2050, and then increasing to 16.9 million hectares by 2100. This change, brought on by human pressure, means that all forest life zones would decrease in size by 2050 and would then experience slight growth towards the end of the century.

According to the HLZ classification, the region has six main forest life zones. They are all tropical forests with different altitudes and humidity levels. The tropical wet forest and the tropical lower montane wet forest are the largest ones, with areas of 12.6 and 5.8 million hectares respectively. Combined, they accounted for almost 65% of the region's natural cover in 2005. The tropical wet forest is located on the Atlantic Coast, Costa Rica's Pacific coast and El Petén in Guatemala. The tropical lower montane wet forest predominates in the central region of Honduras, as well as Nicaragua, Belize, Guatemala's Western Highlands and a small part of El Petén in Guatemala.

In a scenario involving land-use change without climate change, the humid tropical forest could decrease in size to 7.4 million hectares halfway through the century, and then recover to 7.8

million hectares towards the end of it. It is estimated that the tropical lower montane wet forest will have an area of 2.8 million hectares in 2050 and 2.9 million hectares in 2100 (see map 10).

The tropical dry forest, the tropical low montane very wet forest and the tropical very wet forest account for 29% of the region's natural cover. The tropical dry forest grows mainly on the Pacific coast of Nicaragua, El Salvador, Guatemala, and the northern region of El Petén in Guatemala and Belize. The tropical lower montane very wet forest grows in the central region of Costa Rica. The tropical very wet forest thrives primarily in the Autonomous Region of the Atlantic South and Río San Juan in Nicaragua, as well as a small area of Guatemala's Western Highlands.

The tropical dry forest could shrink from 3.2 million hectares in 2005 to 1.3 million hectares by mid-century, to then recover to 1.9 million hectares by the end of the century. The corresponding figures for the tropical lower montane very wet forest are 2.7 million hectares in 2005, 2.0 million hectares in 2050 and 2.1 million hectares in 2100. Similarly, the corresponding figures for the tropical very wet forest are 2.4 million hectares in 2005, 1.7 million hectares in 2050 and 1.8 million hectares in 2100.

The tropical lower montane dry forest, the tropical montane very wet forest, the tropical lower montane rainforest, the tropical montane rainforest, the tropical very dry forest and the tropical montane wet forest are the life zones with the least area. Combined, they accounted for less than 6% of Central America's natural cover in 2005. The tropical lower montane dry forest had an area of 1.1 million hectares in 2005 and could lose 85% of its area in this century, most of it during the next few decades. The remaining areas, which totaled about half a million hectares in 2005, could lose about 58% of their surface area during the course of the century.

To summarize, a scenario of land-use change without climate change indicates that the surface area of all forest life zones will decrease, but that the proportions of the areas will remain relatively constant. It will be important to make progress in the difficult task of estimating the degree or state of conservation of ecosystems.

In order to estimate the potential impact of climate change on ecosystems, this study uses two GHG emission scenarios (B2 and A2), established by the IPCC, and the implications for temperature and precipitation estimated by the ECCCA initiative (ECLAC, CCAD/SICA, UKAID & DANIDA, 2011), including the averages of the following models in particular: HADCM3, GFDL R30 and ECHAM4 for scenario B2, and HADGEM1, GFDL CM2.0 and ECHAM5 for scenario A2. In order to identify trends more clearly, ten year time periods were established for each cut-off year: 2020 (2016-2025 average), 2030 (2026-2035 average), 2050 (2046-2055 average) and 2100 (2091-2100 average).

This analysis estimates how potential changes in temperature and precipitation could change the distribution of forest life zones within the natural surface that is left after land-use changes. It does not estimate how climate change could affect human activities and the consequent rate of destruction of the natural surface, since this kind of analysis requires studies on potential reactions that societies could have in the face of this phenomenon.

The less pessimistic scenario (B2) predicts an average decrease in rainfall of 4% and 11% in most of the region by the years 2050 and 2100 respectively, and an average temperature increase of 1.3°C and 2.5°C for the same years.

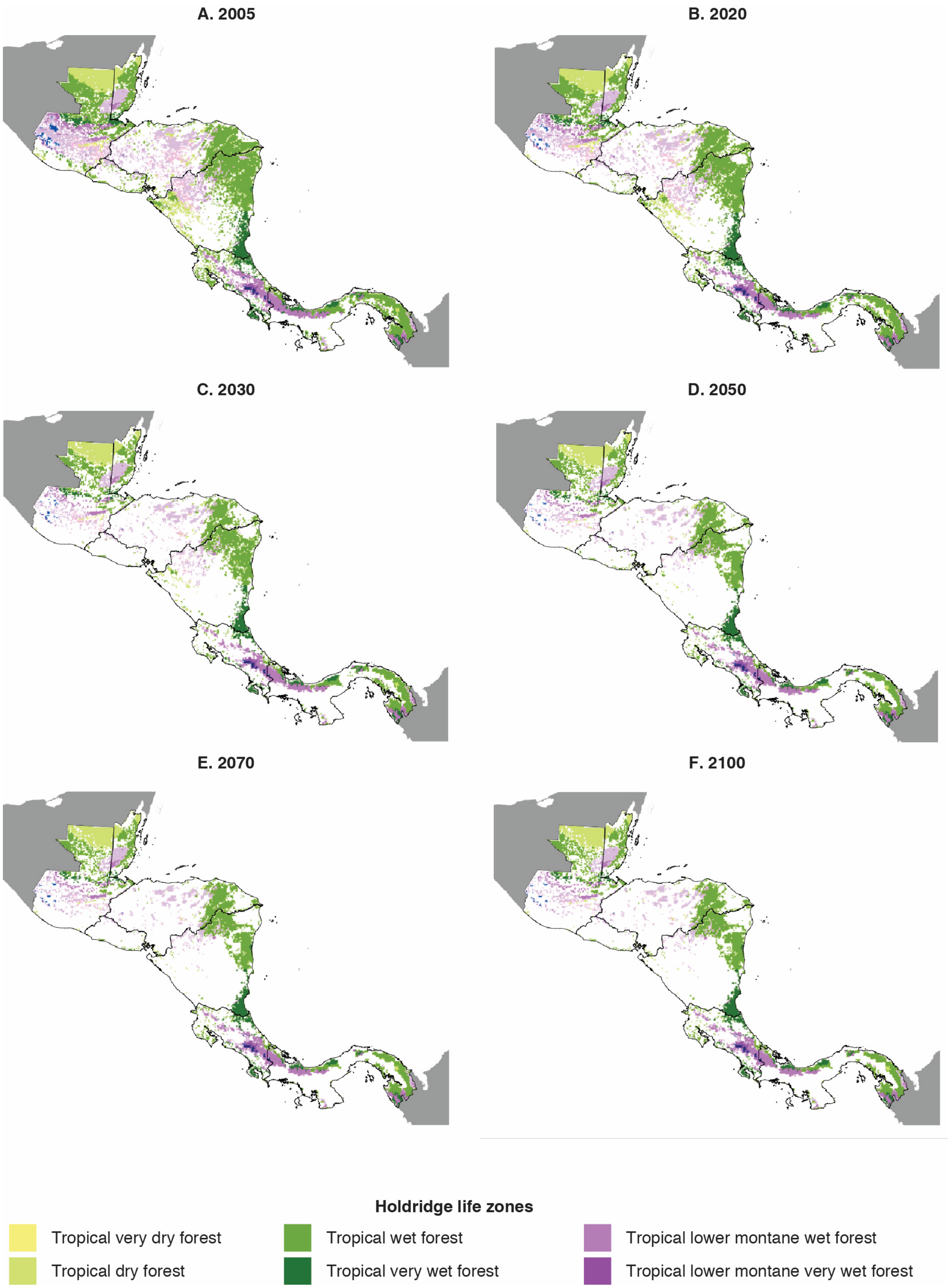
The more pessimistic scenario (A2) predicts a continuous increase in global GHG emissions, resulting in greater average temperature increases of 1.7°C and 4.2°C by the years 2050 and 2100 respectively, and substantial decreases of 14% and 28% in average rainfall by 2050 and 2100 respectively (see Maps 11 and 12).

With regard to potential changes in the six biggest forest life zones in Central America, it is estimated that under scenario B2 tropical wet forests would continue to predominate. Their surface area would fluctuate between 10 million and 14 million hectares during the century, reaching approximately 12 million hectares by 2100. Their proportion of total forest area would increase from 44% in 2005 to more than 70% in 2100. Under scenario A2, it is estimated that tropical wet forest surface area would increase slightly from 12.6 million hectares between 2005 and 2020, but would then shrink during the rest of the century, reaching 7.5 million hectares in 2100, that is, 44% of the total natural surface area, a percentage similar to that in 2005. The tropical dry forest would see the greatest increase in surface area, from 3.2 million hectares in 2005 to 6.6 million hectares in 2100, and its proportion with regard to total forest area would increase from 11% to 39%. These two HLZs would account for almost 84% of total natural surface. The rest of the humid life zones would experience significant decreases; the proportions of tropical lower montane wet forest, the tropical lower montane very wet forest and the tropical very wet forest would decrease from 21%, 10% and 9% of the total in 2005 to 5%, 3% and 4% respectively by the end of the century.

In summary, in scenario A2, the tropical wet forest would shrink in size, while the tropical dry forest would grow. Therefore, the two scenarios indicate different HLZ patterns over time, one of dryer areas (A2), and the other of more humid areas (B2). Both scenarios estimate an increase in humid areas around the year 2020 and a decrease in diversity of the life zones with the passing of the decades. Variations between countries are expected: Belize's tropical wet forest would account for 90% of total forest area in 2100 under scenario B2, while under scenario A2, tropical dry forest would account for 44%. On the other hand, Costa Rica would experience similar patterns in all three scenarios (LUC, B2 and A2) and would maintain greater HLZ diversity (see Figure 22).

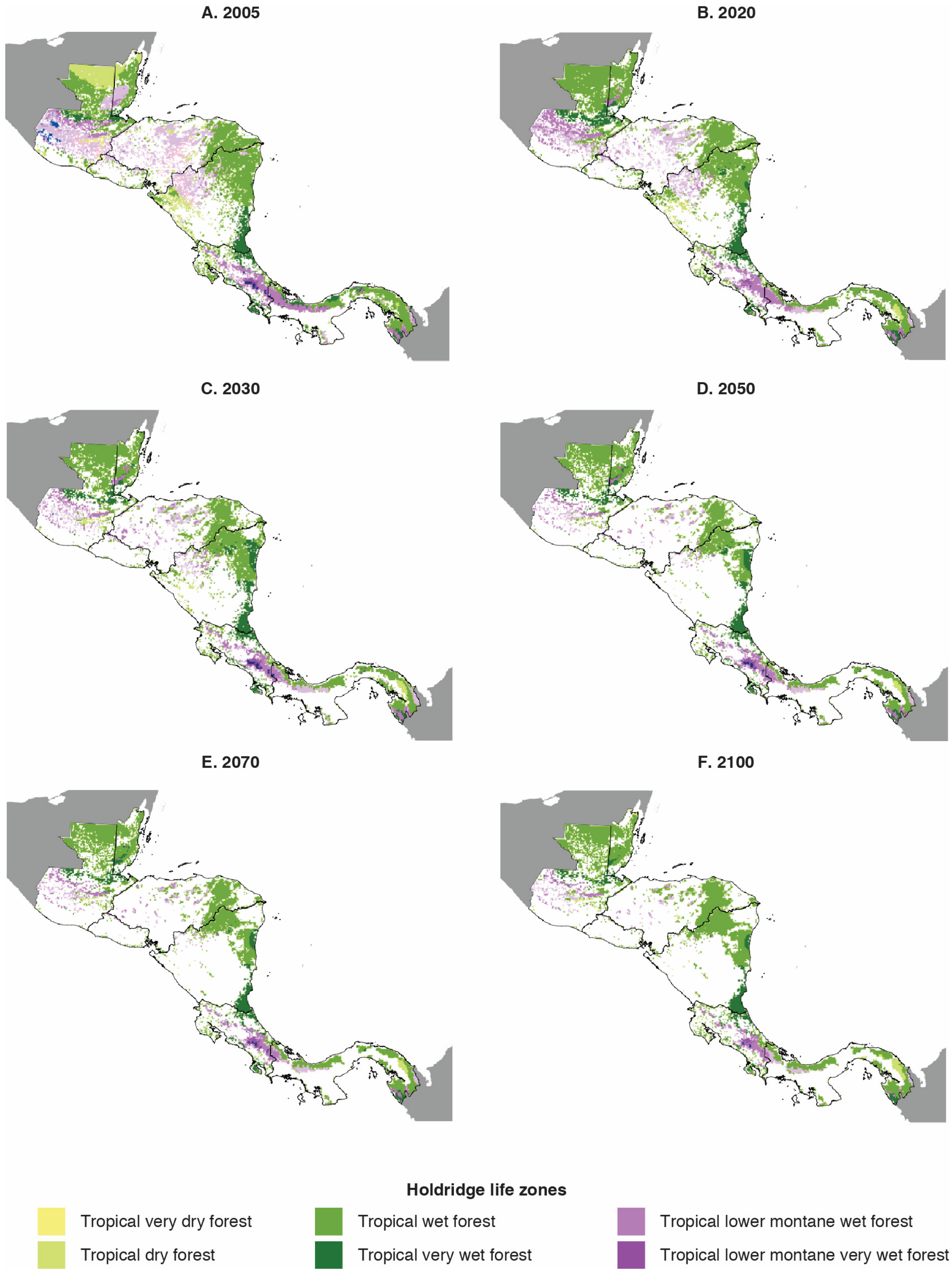
The second part of this study continues the effort made the ECCCA initiative to systematize available information about the economic valuation of ecosystems and their biodiversity in order to estimate current values and future losses attributable to climate change (see chapter 6, ECLAC, CCAD/SICA, UKAID & DANIDA, 2011a). This study uses a meta-analysis technique to establish the estimated economic value of tropical forests. This technique consists of statistical analysis of available empirical studies and their similarities and differences in order to obtain an integrated vision of valuation trends, which are not always captured specifically by individual studies. Since regional studies are scarce, meta-analysis adapts the original information and applies it to other contexts. The combined-effect estimate is a balanced average of the values identified in each study. Greater importance was given to the studies carried out in the region than to those from other parts of the world.

MAP 10
CENTRAL AMERICA: HLZ AREA, 2005 AND LAND-USE CHANGE UP TO 2100



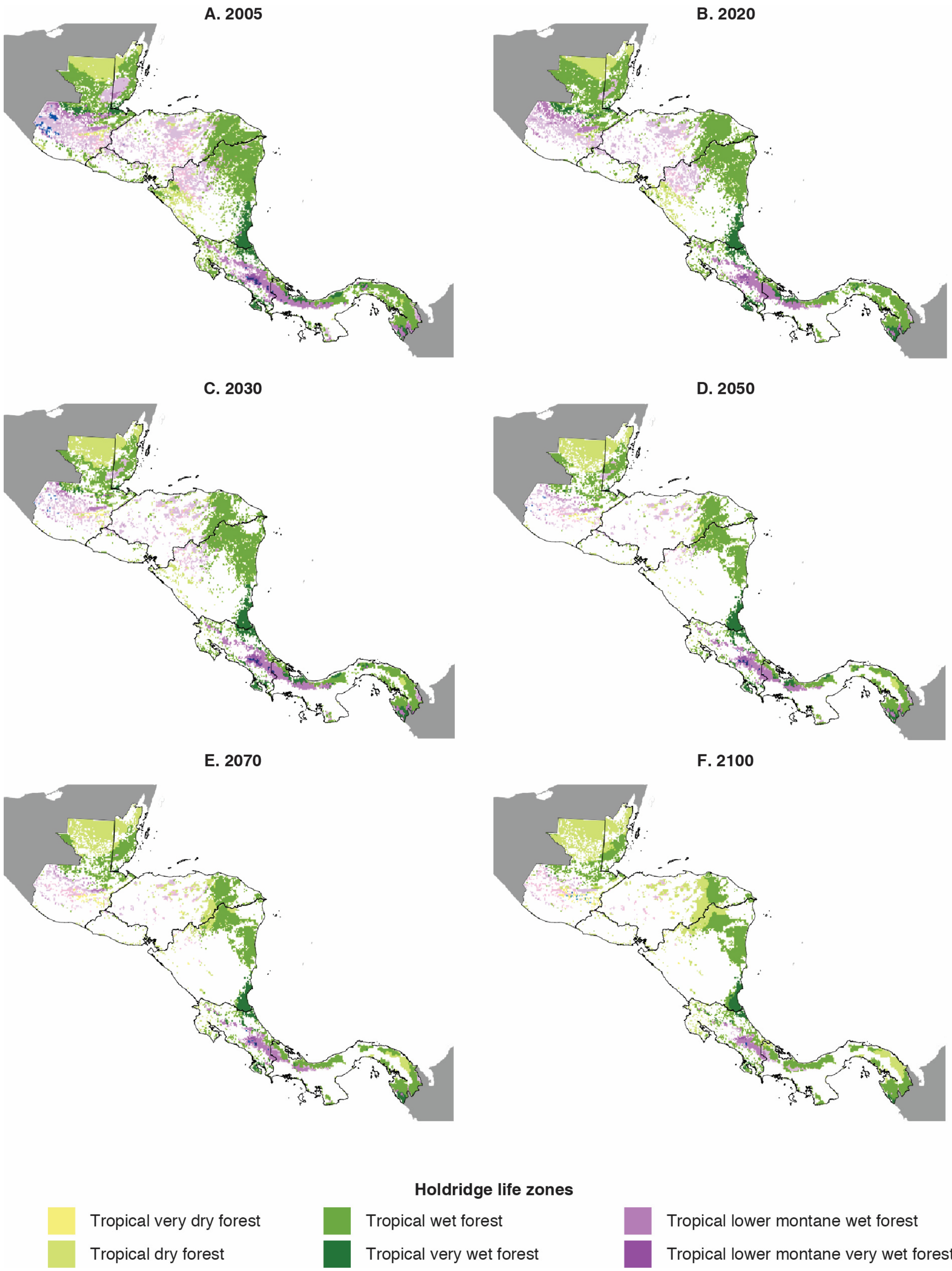
Source: Prepared by the authors.

MAP 11
CENTRAL AMERICA: HLZ AREA, 2005 AND LAND-USE CHANGE WITH SCENARIO B2 UP TO 2100



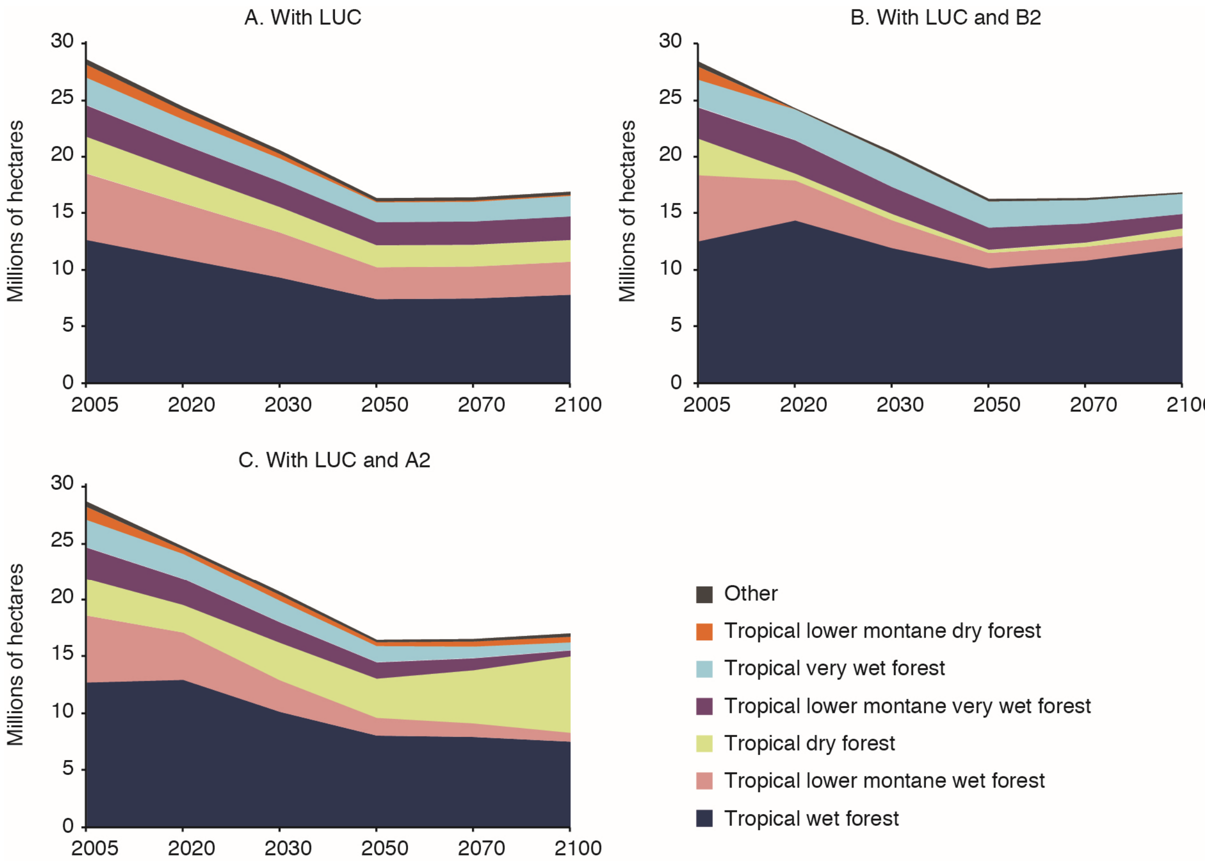
Source: Prepared by the authors.

MAP 12
CENTRAL AMERICA: HLZ AREA, 2005 AND LAND-USE CHANGE WITH SCENARIO A2 UP TO 2100



Source: Prepared by the authors.

FIGURE 22
CENTRAL AMERICA: HLZ AREA, 2005 AND PROJECTIONS UP TO 2100
(Millions of hectares)



Source: Prepared by the authors.

Eighty studies on the economic valuation of ecosystem services provided by tropical forests in various countries were identified. Some studies address more than one service, leaving 275 studies with useful observations for our purposes. Of these studies, 22% are about Central America, 23% about South America, 35% to specific countries in other regions of the world and 20% are global in scope. Most of the studies (44%) use the contingent valuation method, 28% are meta-analyses, 14% are market analysis and 10% are cost-benefit analyses. Approximately 64% address provision and regulation services, while the rest address support services (23%) and cultural services (13%). All estimates were expressed as value per hectare per year in year 2000 dollars.

Two meta-analyses were carried out for each of the six HLZs from the most representative tropical forests. The first estimates the average value per hectare of a "generic" ecosystem service (see the results of another study titled *The Economy of Climate Change in Central America: Potential Impacts on Ecosystems*, part of the 2012 Technical Series).

The second analysis estimates the sum of the average value per hectare of each of the four types of ecosystem services studied: provision, regulation, support and cultural, for each life zone. In other words, the economic valuation is divided by service and type of life zone. These values are used to determine the average value per hectare for each type of service in each life zone. When

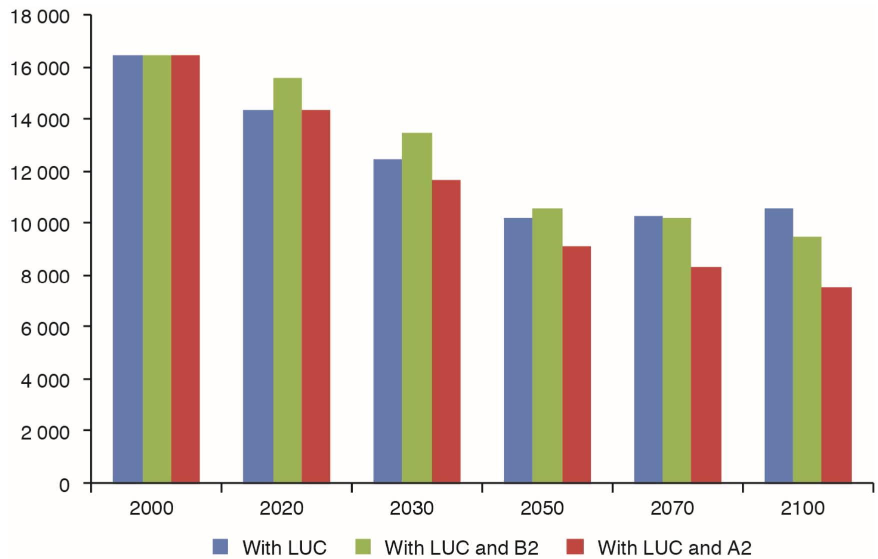
adding these four averages, it is assumed that each hectare can provide the four types of services at the same time without degradation of the ecosystem. To minimize the risk of negative externalities, the value of timber extraction was excluded. Estimates vary between 330 dollars and 355 dollars per hectare per year for tropical very dry and tropical dry forests, respectively; approximately 435 dollars per hectare per year for tropical wet forest; 570 dollars for tropical lower montane wet forest; 1100 dollars for tropical very wet forest and just under 1420 dollars for tropical lower montane very wet forest (this last value is the highest of the estimates and includes a single study in the support services category which provided an estimate of 1064 dollars per hectare per year).

The progression from lower to higher values per hectare as one moves from dry HLZs to the most humid is similar in both analyses, but both have limitations. The first analysis is based on the average of all values for each HLZ, as though each hectare provided just one "generic" service. The second analysis determines average values for four kinds of services for each HLZ, which are then summed, meaning that each average has fewer sources of reference. Similarly, it is assumed that it is possible to use all four services at the same time. As mentioned before, all ecosystem services have not yet been identified and valued, so the values presented should be considered exploratory, with the goal of representing the losses that can be linked to climate change.

Given that the goal of the ECCCA initiative is to warn of the potential impacts of climate change, the second analysis estimates losses in value due to changes in the surface areas of the six HLZs of the region, by HLZ and by country under both climate change scenarios. It is important to mention that the estimates of potential changes in HLZ due to climate change contain a degree of uncertainty and are difficult to establish with precision with respect to changes in location and size. It is also important to note that a significant portion of ecosystem services has not yet been valued. Therefore, the results of the study should be seen as indications of trends, and not exact figures, and serve primarily to compare relative losses of the scenario of land-use change without climate change and the two climate- change scenarios (A2 and B2).

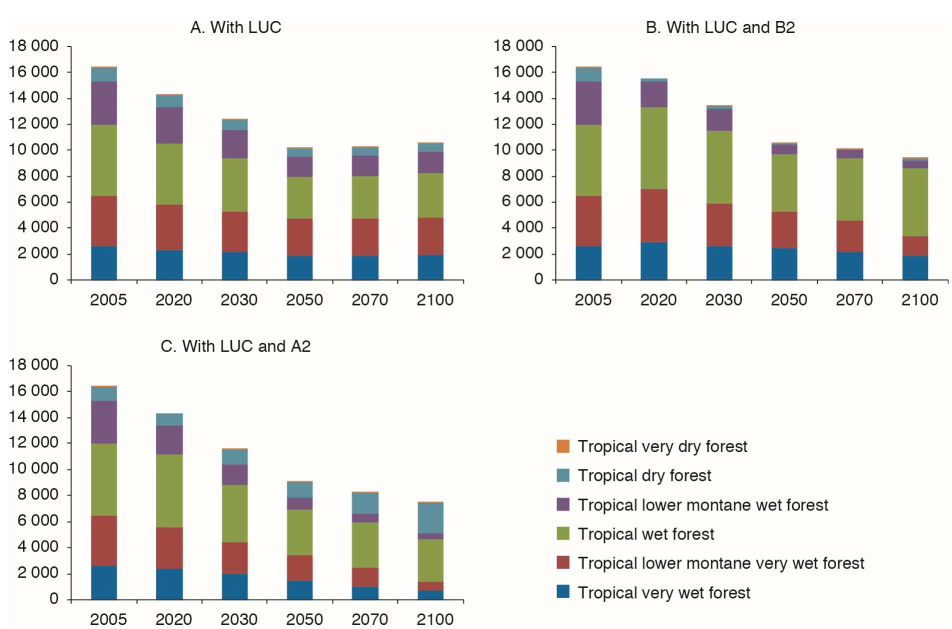
In summary, the estimated annual value of the four types of ecosystem services in the six HLZs was approximately 16.5 billion dollars in 2005. Considering values in year 2000 dollars, under the land-use change scenario the value of the four types of services would decrease to 10.3 billion and 10.6 billion dollars in 2050 and 2100, respectively. Adding the less pessimistic scenario (B2) to the effects of the land-use change scenario, values would be 10.6 billion and 10.9 billion dollars in 2050 and 2100 respectively, with a 3% increase by 2050 due to the increase in wet forests in this initial period, and a 10% decrease by 2100, as compared to the land-use change scenario only. With the combination of the land-use change scenario and the more pessimistic scenario (A2), total values would be 9.1 billion and 7.6 billion dollars, representing decreases of 11% and 29% relative to the land-use change scenario. In this scenario, the drop in value is linked to a decrease in the surface area of humid forests, which have higher per-hectare values.

FIGURE 23
CENTRAL AMERICA: INITIAL ESTIMATE OF VALUE OF SIX MAIN HOLDRIDGE LIFE ZONES, 2005 AND ESTIMATES UP TO 2100
(Millions of year 2000 dollars)



Source: Prepared by the authors.

FIGURE 24
CENTRAL AMERICA: INITIAL ESTIMATE OF VALUE PER HOLDRIDGE LIFE ZONE, 2005 AND PROJECTIONS UP TO 2100
(Millions of year 2000 dollars)



Source: Prepared by the authors.

The above results could be interpreted as suggesting that ecosystem services might possibly benefit under scenario B2 during the initial decades of the century, but it is important to note the following: the study assesses temperature and precipitation conditions linked to different HLZs, but

it remains to be studied whether the combination of life forms in the different HLZs could actually adapt to the period and rates of change in temperature and precipitation combined with the pressure of land-use change. Furthermore, it is important to mention that the current GHG emissions trend seems to be nearer to scenario A2 than to B2, so it is less likely that this "beneficial" effect will take place. As of 2070 in the LUC scenario combined with B2, and as of 2030 in the LUC scenario combined with A2, there will be losses in value relative to the LUC scenario without climate change.

To conclude, it must be noted that all three scenarios suggest losses in value relative to 2005 estimates: in the land-use change scenario, losses would amount to 38% in 2050 and 36% in 2100; in a land-use change scenario combined with B2, losses would amount to 36% and 42% for 2050 and 2100 respectively; in a land-use change scenario combined with A2, losses would amount to 45% and 54% for 2050 and 2100 respectively. These results confirm that decreasing deforestation and making progress in the protection of natural ecosystems are development challenges in and of themselves, and suggest that climate change, especially in the more pessimistic scenario of increased emissions, would bring about greater losses in forests and the services provided by their ecosystems (see Figure 23 and Figure 24).

This study has estimated the potential changes in ecosystems using the HLZ classification, since the fact that it includes temperature and precipitation variables makes it ideal for modeling the impacts of the different climate change scenarios. This is a first step, since future analyses will face the complex task of exploring the capacity of ecosystems and their member species to evolve, "move" and maintain their integrity under these changing climate conditions. Additionally, it must be remembered that degradation and fragmentation due to direct pressure from societies complicates this adaptation. These future studies can benefit from the analyses of the effects of changes in intra-annual patterns of precipitation, aridity and dry months, available in the other publications of the 2012 Technical Series. The systematization of the various studies on economic value, using meta-analysis, provides results that could be useful for other valuation activities, including the assessment of the impacts of extreme events. It proves the need to incentivize more studies on ecosystem services within the region and options for their valuation, especially in less-studied areas such as the tropical lower montane very wet forest.

Human adaptation to climate change is clearly linked to the adaptation of the ecosystems on which humans depend, especially in regions such as Central America. Responding to this challenge will require incorporating the role of environmental services into the valuation of the efficiency and sustainability of our economic activities, and taking appropriate measures outside the market to generate appropriate incentives and regulatory frameworks. In this vein, the precautionary principle must be applied and minimum standards established given the irreversibility of biological loss, the risk and the uncertainty. Since climate change and the loss of habitat caused by other factors interact in this landscape, it would be advisable to expand and strengthen the system of Natural Protected Areas (there are now over 550 in the region) and biological corridors to encompass a broader bio-geographic area, to give more importance to land management and the definition of protected areas, and to strengthen the protection of climate refuges. These efforts can be complemented with programmes in the areas of sustainable agriculture, sustainable forest use, and the rescue of native crops and wild endemic species that can resist the expected effects of climate change.

6. EVIDENCE OF CLIMATE-SENSITIVE ILLNESSES

The Ministries of Health and the Council of Ministers of Health of Central America and the Dominican Republic (COMISCA) launched the "Health and Climate Change" initiative in 2012 to produce more information on the potential impact of climate change on climate-sensitive illnesses, with the collaboration of ECLAC, the Pan-American Health Organization (PAHO) and other expert organizations, such as the Gorgas Memorial Institute of Health Studies (ICGES) in Panama, the Meteorological Institute of Cuba (INSMET) and the National Institute of Public Health (INSP) in Mexico.

An exploratory study was prepared in the framework of this initiative to analyze the correlation between climate and the incidence of the main diseases of Central America, the results of which are summarized below (ECLAC, COSEFIN, CCDA/SICA, COMISCA, UKAID and DANIDA, 2012). The study considers the direct and indirect repercussions of extreme meteorological events and changes caused by the climate. The study reviews the related literature from scientific indexed journals and other non-indexed documents in order to compile more background information for future research. The illnesses considered are: dengue, malaria, diarrhoeal diseases (DD), acute respiratory diseases (ARD), Chagas disease, leishmaniasis and leptospirosis. The study searched for analyses correlating the incidence of these illnesses with temperature, precipitation or air pollution events or trends. The period of time considered was 1960-2012 using scientific sources of information (MEDLINE, COCHRANE and LILACS), along with databases (Pubmed, EBSCOhost web's Academic Search Premier and Scielo) and Google's academic search engine. The study also includes an analysis of the vulnerability of the health sector.

Historically, Central American countries have faced both the direct and indirect health effects of hydro-meteorological phenomena. In recent years, there has been growing concern regarding the increasing intensity and number of these events due to climate change. Besides their immediate effects, natural disasters also have serious secondary effects that affect public health due to floods, destruction of crops and the re-location of those affected to small unsanitary spaces (Noji & Toole, 1997). This is in addition to the existing poor living conditions including housing, public health and environmental infrastructure, which place the health of the population in a high state of vulnerability even without climate change. Of the approximately 41 million inhabitants of Central America, two thirds live in settlements that combine poverty with unsanitary conditions and deficient basic sanitation and health services (FAO-ETEA, 2008). In fact, some diseases related to poverty, such as malaria, dengue, intestinal parasitic infections, Chagas disease, leptospirosis and leishmaniasis, are also associated with changes in climate (Hotez and others, 2008). At the same time, Central America is home to a mosaic of ecological niches that are ideal for the transmission of diseases associated with the region's orography and climate, since the isthmus is narrowly bordered by the Atlantic and Pacific oceans.

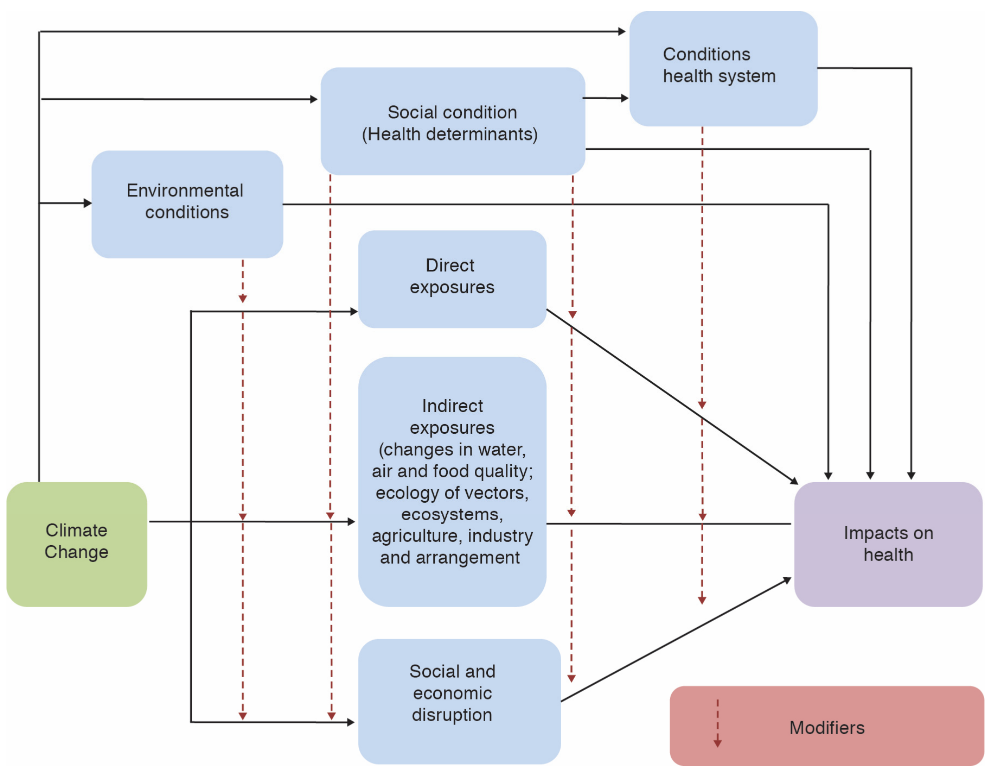
To assess the relationship between climate and health, the World Health Organization (WHO) has used epidemiological studies based on chronological temperature and precipitation data as well as data on disease and mortality in geographically delimited populations (WHO, 2008). To

assess the state of health of certain populations, the WHO examined events attributed to short-term meteorological variations, including the direct impacts of heat and cold, availability of food, impacts of hydro-meteorological events, illnesses related to atmospheric pollution, and vector-, water-, and food-borne and zoonotic diseases.

The UN Framework Convention on Climate Change (UNFCCC) considers the improvement of public health systems, especially epidemiological monitoring systems, a fundamental prerequisite for the adaptation of human health to climate change. To achieve this, it is necessary to evaluate the capacity for recovery and response of the health sector in the face of events caused by climate change and variability. A comprehensive evaluation that considers the possible interactions between the different factors in the most vulnerable situations (interculturality, infrastructure, poverty and inequality) is needed. The potential repercussions on the health sector caused by food security, malnutrition, migration, spread of diseases and the increase in poverty also need to be determined.

In the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 2007d), the "Impacts, Adaptation and Vulnerability" work group stated that impacts can be direct or indirect, that they can occur through different channels and that their association with climate variables can be modified by environmental, social or health system factors (see Diagram 1).

DIAGRAM 1
WAYS IN WHICH CLIMATE CHANGE AFFECTS HUMAN HEALTH



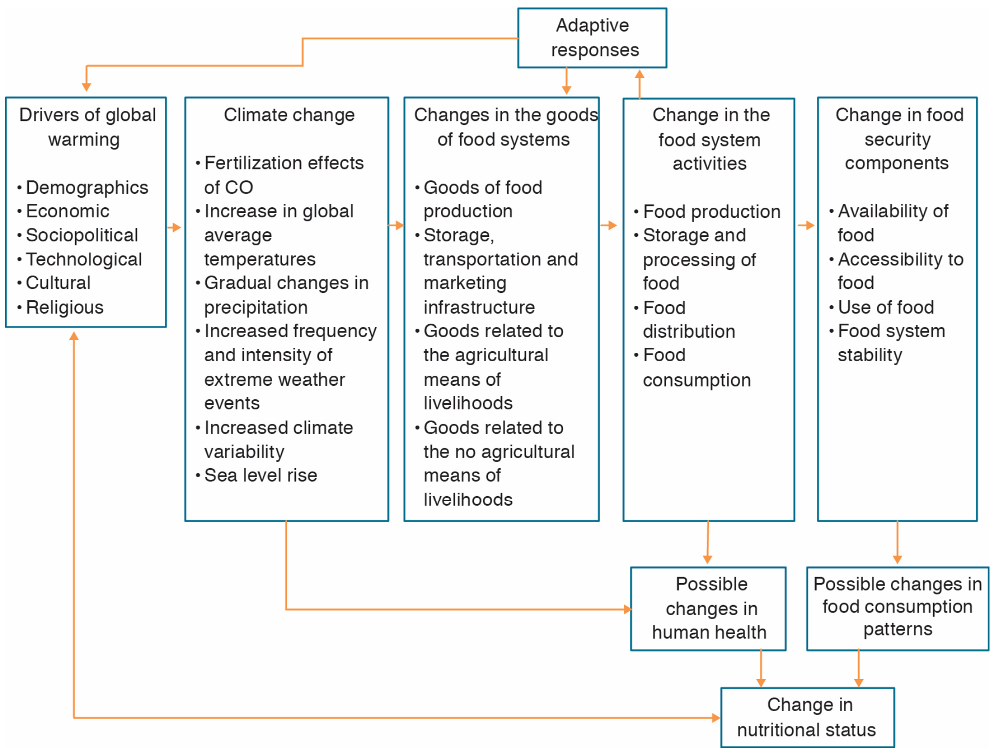
Source: IPCC, 2007.

The most obvious direct impact of climate change on human morbi-mortality is linked to extreme temperatures. Europe's heat wave in 2003 brought about a health, political and social crisis that evinced deficiencies in the epidemiological monitoring systems of several developed countries. This event spurred the evaluation of the impact of extreme temperatures on morbi-mortality on the

continent[5]. It was found that, despite the heterogeneity of the analysis methods, the groups most affected by exposure to high temperatures were consistently people older than 75, people with prior illnesses or those who lived alone, the poor, and people with an overall low socioeconomic status. These findings laid the foundation for the development of early alert systems aimed at reducing the morbi-mortality associated with high temperatures.

Various international studies have quantified the impacts of climate change on global food security. The assessment of the effects of climate change on health due to availability of food on a global scale is in its early stages. In the past year a number of studies have been carried out quantifying the negative impact of climate change on agricultural yields and production in Central America, including the production of grains fundamental to food security, such as maize, beans and rice. Since food insecurity includes a lack of food and inadequate nutrition, it is recommended that the studies include all the factors that form part of the food system (see Diagram 2).

DIAGRAM 2
EFFECTS OF CLIMATE-CHANGE ON FOOD SECURITY



Source: FAO, 2007.

The indirect impacts of climate change on human health are mediated by changes induced in complex biogeochemical processes and other health-related environmental risk factors. Climate change has been associated with an increase in the intensity of extreme hydro-meteorological events (EHEs), which often cause significant material and human losses. Figure 25 illustrates the economic losses caused to the Central American health sector by the most significant disasters.

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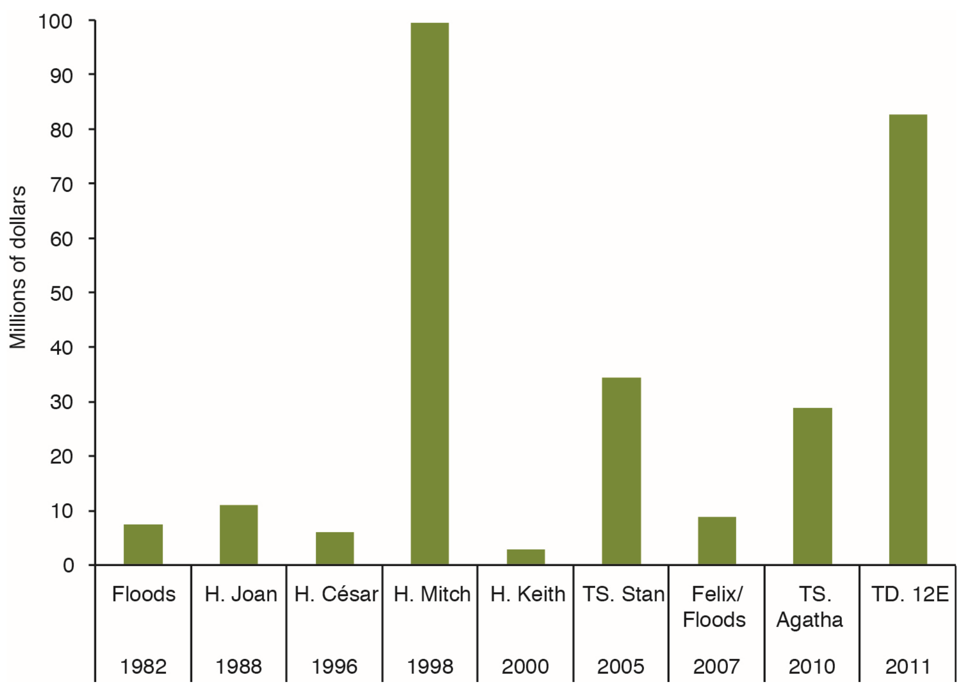
[5] See ECLAC, COSEFIN, CCAD/SICA, COMISCA, UKAID and DANIDA, 2012 to consult the bibliographic sources of studies of various illnesses dealt with in this section.

The most devastating hurricane in Central America was Mitch (1998), which left approximately 30,000 people dead or missing, and caused significant economic loss, destroying housing, bridges, roads and a large part of coffee and banana plantations (Cupples, 2007). The damage caused by EHEs and the floods that follow to the infrastructure for communication, sanitation and basic services such as lighting, potable water and health services can create favorable conditions for the spread of multiple infectious diseases, such as cholera, dengue and diarrhoea (Schultz and others, 2005). The flooding of crops causes food shortages while contaminating the soil. The affected population can develop mental health disorders, such as post-traumatic stress disorder and depression (WHO, 2008).

FIGURE 25
CENTRAL AMERICA: ECONOMIC LOSSES IN THE HEALTH SECTOR CAUSED BY DISASTERS
(Millions of year 2008 dollars)



Source: CEPAL, several years.

Temperature increase in cities with atmospheric pollution is an important aspect of climate change, since climate conditions directly affect the accumulation and spread of pollutants. Two of the most harmful pollutants are ozone and particulate matter; both are sensitive to the climate, but ozone is especially so. Ozone is a secondary pollutant formed in the atmosphere through reactions between primary pollutants such as nitrogen oxides and volatile organic compounds in the presence of solar light (radiation). The high number of people aged 65 and over being hospitalized for respiratory illnesses, asthma and chronic obstructive pulmonary disease is linked to the increase in the concentration of ozone. During several heat waves in London in 2003, 2005 and 2006, an additional 6000 deaths were attributable to ozone levels and 5000 deaths were directly related to temperature.

Central American cities do not have similar studies due to a lack of health data and, in some cases, a lack of atmospheric monitoring. The cities of the region need special attention as the population has grown disproportionately; this trend, combined with economic factors, increases levels of pollution. The main sources of emissions are obsolete automobiles and the use of low-quality fuels (Swisscontact, 2000). In order to improve air quality in Central American urban areas,

atmospheric monitoring stations have been built, and measures, such as using un-leaded fuel, have been implemented to reduce the emission of pollutants. Costa Rica banned the use of leaded petrol in 1996 and established annual vehicle inspections, thus managing to reduce levels of metal in the atmosphere by 60% (Onursal and others, 1997).

Acute diarrhoeal diseases (ADDs) follow seasonal patterns and their greatest incidence coincides with hot periods, when pathogenic agents proliferate. Changes in global precipitation patterns also contribute to the outbreak of these diseases. In tropical countries, viral infections occur throughout the entire year, worsening during the dry season and the coldest months. Bacterial diarrhoea frequently occurs most frequently during the warmest months of the rainy season. The El Niño-Southern Oscillation (ENSO) has been identified as a factor that influences EHEs, which are associated with an increase in hospital admissions due to ADDs. It has been shown that most emergency hospital admissions due to gastrointestinal infections are related to the turbidity of drinking water. Other studies show a link between ADDs and the consumption of raw, insufficiently-cooked or contaminated shellfish, with greatest incidence during the warm months. Some studies suggest that climate change could affect human health due to its effect on the harmful blooming of phytoplankton in surface waters, estuaries and coastal waters. Other studies report that this blooming could be aggravated by changes in sea surface temperature (SST), which, combined with the strength of the wind, contributes to the spread of toxic phytoplankton and human intoxication through mollusc consumption.

Poor basic sanitation, poor quality of water for human consumption and fecal contamination of foods persist in Central America, allowing diarrhoea caused by intestinal infections to thrive. Economic inequality in Central America is reflected in the imbalanced access to water and sanitation. For example, more than half of Nicaragua's population lacks access to basic sanitation services and has limited access to medical attention (IDB, 2007).

Zoonoses are diseases that are transmitted by vertebrate animals to humans, and some varieties follow seasonal patterns. Changes in temperature and precipitation patterns influence the dynamics of wild and, to a lesser degree, domestic fauna, in turn influencing the transmission of diseases. Leptospirosis is one of the most common zoonotic diseases, and is caused by pathogenic spirochaete of the genus *leptospira,* whose vectors or carriers are animals. Human infection occurs through accidental contact with carrier animals or with contaminated environments; the main source is usually the urine of the excreting animal, frequently rats, dogs, and bovine, equine, and porcine animals. The majority of leptospirosis infections are mild and have a quick recovery period; however, a small percentage develops complications due to the involvement of multiple bodily systems, and the mortality rate in these cases is approximately 40% (Ashford and others, 2000). Leptospirosis outbreaks have occurred in Nicaragua, Brazil and India during the last few years, and some of them were caused by flooding following hydro-meteorological events (Vijayachari and others, 2008).

During the last two decades there has been a debate about the effects of climate variables on vector-borne diseases (VBDs). The influence of temperature and rainfall on VBDs is well documented; the most studied diseases are dengue, malaria, Chagas and leishmaniasis.

Dengue is the most common arboviral disease in the world. Transmission occurs through the sting of the yellow fever mosquito (*Aedes aegypti*) through four serotypes: DEN-1, DEN-2, DEN-3 and DEN-4. This disease spreads primarily in the tropics, where, it is estimated, between 50 million and

100 million people are infected annually (Wong and others, 2007). Dengue has seen a significant rise in recent decades in practically all of Latin America, where all four serotypes currently abound. The risk of dengue hemorrhagic fever has increased in Central America (WHO, 1992).

As with other VBDs, dengue has a clear seasonal pattern; temperature and precipitation promote the spread of mosquitoes and increase the probability of human transmission of the virus. Hales and others (1999) researched the relationship between the incidence of dengue and ENSO events in 14 island nations of the Pacific using correlations of annual averages of the Southern Oscillation Index (SOI), local temperature, precipitation and number of cases of dengue. The authors found a positive correlation between the SOI and dengue on ten islands and a weak or negative correlation between SOI and dengue on four islands. Similarly, Gagnon and others (2001) established a temporal correlation between ENSO events and dengue epidemics in French Guyana, Indonesia, Colombia and Surinam. Monthly temperature and hydrological data (precipitation and river height) from the same study show that the dengue epidemics in the northern part of South America are associated with warmer temperatures and decreased precipitation in El Niño years. Other studies have analyzed small geographical areas with aggregated weekly data, and have evaluated temperature and precipitation variables as the primary factors in the biological processes that affect health.

Malaria is one of the biggest global public-health problems because of its high level of incidence, broad area of transmission and economic costs. In 2008 there were 247 million cases in the world and almost one million deaths, mainly in Africa's infant population (WHO, 2010). Malaria is transmitted to humans from parasites of the genus *Plasmodium* through the sting of an infected *Anopheles* mosquito. There are about 400 *Anopheles* species, of which about 30 to 40 can transmit four species of parasites capable of infecting humans.

Vector abundance is related to places that favour the larval development of mosquitoes, which in turn depends on topography, hydrology, rainfall, temperature and the abundance of blood-sucking animals. This relationship was identified through a study that was carried out in Sucre, Venezuela; this study correlated malaria cases with climate variables for a period of 15 years (1986-2000). Results showed that temperature, precipitation and humidity affect vector biology and ecology, reducing its extrinsic incubation period (EIP), i.e. the time needed for a pathogen to become infectious (Delgado and others, 2004). Other studies have shown that high temperature and rainfall could widen the transmission radius of the diseases and modify its patterns.

Chagas disease, or *American tripanosomiasis*, is endemic to Latin America and mainly affects inhabitants of poor areas of Central and South America. It is a parasitic disease caused by *Trypanosoma cruzi*, a protozoan flagellate that is transmitted to humans through the excretion left (following the sting) by certain hematophagous arthropodic insects of the *Triatominae* subfamily, or through other routes, such as blood transfusions, organ transplants, consumption of contaminated food or from a pregnant women to the fetus. *Triatoma dimidiata* is the main vector in Central America, abounding in Guatemala, El Salvador, Nicaragua and Costa Rica, and it is the second most significant in Honduras and Colombia after *Rhodnius prolixus* (Dorn and others, 2007).

The vector's habitat and dispersal patterns are determined by climate and geographic factors. Triatoma survives in warm climates with temperatures between 16°C and 32°C. Some studies show that high temperatures could accelerate the triatoma's metabolism, while a low concentration of

relative humidity could provoke its dehydration, which would increase its feeding frequency since blood contains a significant amount of water (Carcavallo, 1999). Therefore, the global increase in temperature could affect the prevalence of the disease in endemic areas, even in those where it is believed to have been eradicated (WHO, 2002). The prevalence of the vector in areas with cold winters can be attributed to its ability to survive in micro-climates that are warmer than ambient temperature, such as homes and the interior of certain plants. Forest logging and the increase in temperature can promote the spread of the wildlife reservoir and *T. cruzi* vectors towards areas of greater human concentration.

Leishmaniasis is a parasitic disease caused by more than 20 protozoan species from the genus *Leishmania*. It is transmitted to humans and animals through the bites of female hematophagous insects of the *Phlebotominae* family, which includes the genuses *Phlebotomus* and *Lutzomia* in Europe and Latin America, whose chances of survival are greater in warm, humid climates (Auzpurua and others, 2010). Humans can be infected by parasites from animal reservoirs or by parasites from another human vector. The clinical manifestations of leishmaniasis are: cutaneous (CL), American cutaneous (ACL), mucocutaneous (MCC), diffuse cutaneous (DCL) and visceral (VL). Cutaneous manifestations are also known as American Tegumentary Leishmaniasis (ATL). Cutaneous leishmaniasis presents in a non-ulcerated form known as atypical cutaneous leishmaniasis (Nogueira and others, 2005). The most prevalent CL, VL and ACL agents in Latin America are *L. braziliensis*, *L. guyanensis*, *L. panamensis*, *L. Mexicana* and *L. infantum*, which are primarily transmitted by canine species to humans via vectors of the genus *Lutzomia*. Each species presents different demographic and epidemiological patterns. Argentina, Bolivia, Brazil, Colombia, Mexico, Peru and Venezuela are the countries most affected. VL is endemic to areas of Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua (PAHO, 2007).

Assessment of the vulnerability present in climate-variability allows the relationship between exposure to climate factors and the response to some climate-sensitive diseases to be understood. The results can serve as instruments to implement adaptation interventions or measures to mitigate the toll taken by such diseases. Ortiz and other (2006) provide a good example of this with their study that evaluates the potential effects of climate-variability on different public health events in the Cuban population. The study looks at acute respiratory infections, acute diarrhoeal diseases, bacterial and viral meningitis, dengue and bronchial asthma, and demonstrates that official monthly data can offer useful information to decision makers.

Studies of vulnerability to climate change should identify the processes that determine climate variability in order to identify the conditions that magnify risks and damages. Some methods to assess vulnerability of the health sector found in recent literature are: *Modeling Framework for Health Impact Assessment of Man-Induced Atmospheric Changes* (MIASMA); Estimating the global burden of disease; *UNFCCC Guidelines Methods to Assessing Human Health, Vulnerability and Public Health Adaptation to Climate Change*; *Lym Sim*; Livelihood Vulnerability Index; and Hydro-meteorological disaster vulnerability syndrome.

Research on the potential damage to health caused by climate change requires that, when the effects of climate are observed using epidemiological methods, other variables be considered, such as determinants of disease and vulnerability of the population studied. Therefore, epidemiological scenarios associated with climate change need to be created, and these scenarios need to consider three interrelated variables: climate variables that are related directly or indirectly to health,

variables related to the etiology of each disease, and variables of the population's vulnerability to climate change. Some studies include demographic variables; others develop complex indices to reflect climatic anomalies in different scales, which is why they incorporate ecological and social information to explain the mechanisms and the relationship between climate conditions and disease.

The potential impacts of climate change on health in Central America include growing stress due to heat, and changes in the patterns of diseases such as malaria, dengue and cholera. Malaria continues to be a serious health risk in most of Central America, including the entire territory of El Salvador (PAHO, 2002). Some projections suggest probable decreases in malaria during its transmission season in areas where a decrease in rainfall is expected. Nevertheless, in Nicaragua, it is expected that there will be an increase in the incidence of the disease. In Guatemala, the potential impact of climate change on acute respiratory infections, acute diarrhoeal diseases and malaria was studied. It was found that these diseases might not continue to follow their traditional seasonal patterns. In Panama, an early warning system that analyses the incidence of the dengue-transmitting mosquito allows the health sector to run its community vector control programme and other activities to reduce the number of cases. A recent study in Costa Rica analyzed dengue, malaria, asthma, heart disease, diarrhoea and parasitic diseases according to vulnerability in terms of sensitivity, exposure and resilience (see Box 1, Box 2 and Box 3).

BOX 1
GUATEMALA: EFFECTS OF CLIMATE, CLIMATE VARIABILITY AND CLIMATE-CHANGE ON HUMAN HEALTH

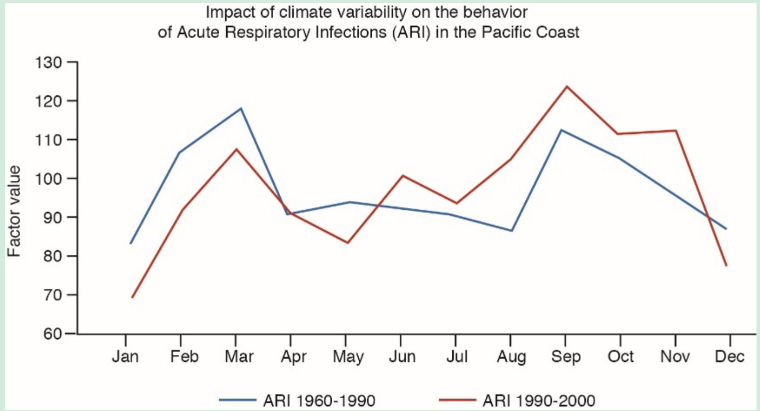
This study was carried out in the framework of the First National Communication on Climate Change, and includes an evaluation of the potential impacts of climate change on public health in Guatemala. Firstly, the study considers that human health is the result of interactions between many factors, such as (1) human biology, (2) the environment, (3) socioeconomic situation, (4) habits, traditions, and lifestyles of people and communities, and (5) the condition of socio-healthcare infrastructure, particularly health services.

The study focused on three diseases: acute diarrhoeal diseases (ADDs), acute respiratory infections (ARIs), and malaria (MA). These three diseases are the most prevalent in the population according to official data from the Ministry of Public Health. The first two are infectious while the third is vector-borne.

The study found that the diseases considered will not follow their historic seasonal patterns and that epidemic episodes will occur outside the normal season. With regard to ARIs, the periods 1960-1990 and 1990-2000 were analysed, looking at the number of reported cases of illness and the climatic variation in each period. In the period 1960-1990, ARIs showed a bimodal behavior with a sharp peak in March and another peak in September-October. It is possible to see an increase in frequency at the start of the rainy season (June and July) but also a delay in the occurrence of the epidemic episode typically seen at the end of summer (blue line). In a climate change scenario, this disease would not follow its historic seasonal pattern; instead, there would be epidemic episodes or notable decreases in incidence outside the normal season (red line).

(continued)

Box 1 (Conclusion)



Impacts are more pronounced during ENSO years (Glantz, 1998; Epstein, 1999) as the frequency of cold waves and the thermodynamic features of the air masses that follow change. The occurrence of warmer and dryer periods is another consequence of ENSO in Guatemala.

The impacts of climate change on human health are reflected in:

- An increase in mortality and morbidity indices.
- An increase in infectious and non-infectious, vector-borne and non-vector-borne diseases (malaria, dengue, schistosomiasis).
- An increase in malnutrition and dehydration indices due to difficulties accessing water and food.
- Damages to public health infrastructure.
- Psycho-somatic effects caused by climatological phenomena.

Source: First National Communication on Climate Change (MARN, GEF, UNDP, 2001).

BOX 2
PANAMA: EARLY WARNING SYSTEM FOR DENGUE

The Gorgas Memorial Institute for Health Studies, the Empresa de Transmisión Eléctrica S.A. [Electric Transmission Company], the Ministry of Health and the National Census and Statistics Institute, advised by the Climate and Health Unit of the Institute of Meteorology of Cuba, have created a Mosquito Infestation Index (INDINF), applying the Bultó-Index (BI) mathematical-statistical model to predict the likelihood of infestation of the *Aedes aegypti* mosquito in the district of Panama in the next three months.

INDINF is an observational, descriptive and retrospective index that combines historical entomological and climatic variables with geographical information technology. Time series of entomological variables (mosquito infestation index) and climatic variables (atmospheric pressure, rainfall, maximum and minimum air temperatures, monthly thermal oscillation, relative air humidity, wind speed at ten meters, vapor pressure, number of days of precipitation and insolation, i.e. hours of sun) were used.

(continued)

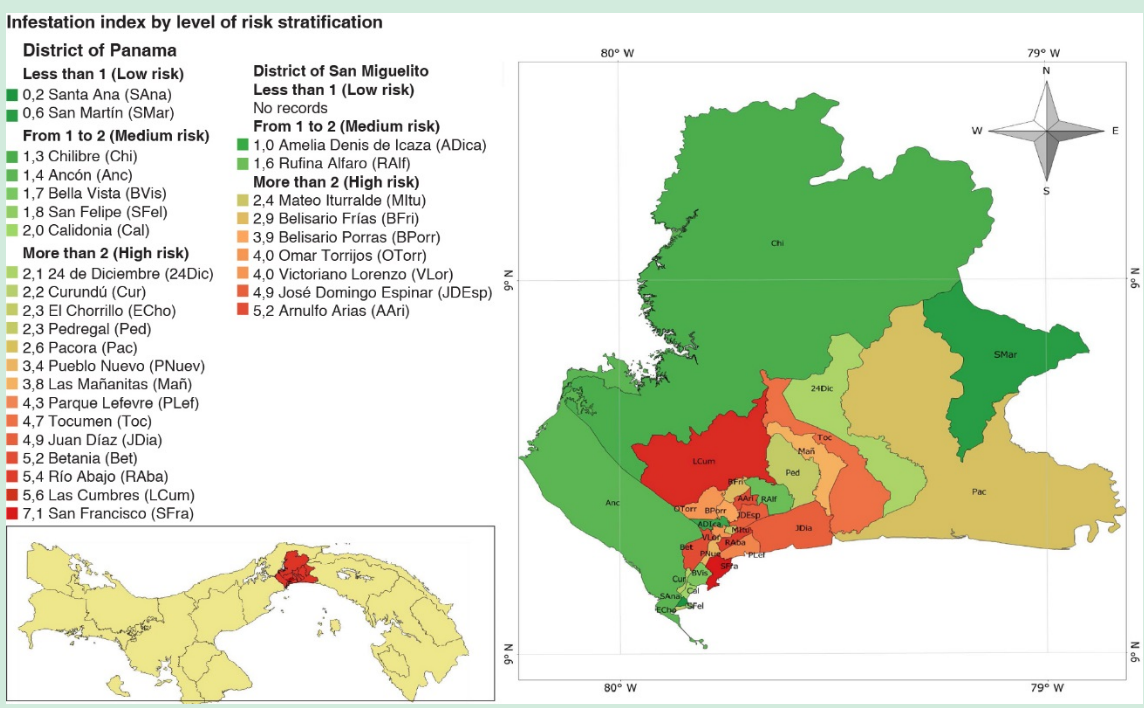
Box 2 (Continuation)

The entomological variables are obtained from the Entomological Survey carried out every four months by vector control inspectors and/or vector technicians. In 2011, 73,123 properties were inspected; of these 912 had positive results, resulting in an index of 1.2%.

A monthly report provides the indices of observed infestation and predictions per month and quarter, as well as monthly georeferencing for the capital district. The following map shows infestation index predictions for August 2012 for the districts of Panama and San Miguelito, where the red areas represent the areas of highest risk. According to this report, a decrease was predicted relative to July values since the BI predicted less humidity, warmer temperatures and lower-than-normal rainfall values. The infestation index prediction depends on past behaviour, as well as the BI and MEI (Multivariate ENSO Index) measured by the U.S. National Oceanic and Atmospheric Administration.

Thus, it has been possible to predict *Aedes aegypti* infestations by month and quarter in the district of Panama, which allows the National Health System to react with health interventions that reduce the risk of dengue in the country. The results show that predicted infestation index values follow the same trend as observed values. For the majority of the year, the predictions were slightly higher than observed values, as can be seen in the following figure.

DISTRICTS OF PANAMA AND SAN MIGUELITO: INFESTATION INDEX FORECASTING, AUGUST 2012

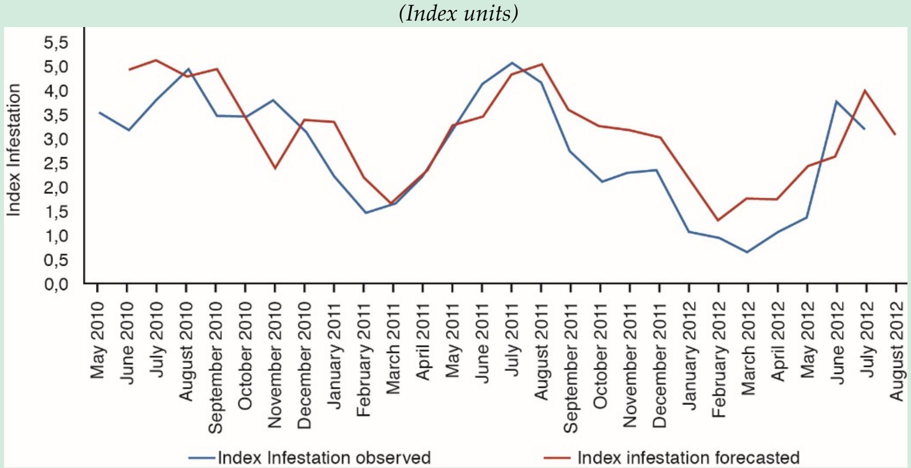


(continued)

Box 2 (Conclusion)

PANAMA DISTRICT: COMPARISON OF FORECAST AND OBSERVED INFESTATION INDEX MAY 2010-AUGUST 2012

(Index units)



Source: ICGES, ETESA, MINSA e INEC (2010), MINSA (2011) y ICGES, ETESA y MINSA (2012).

BOX 3
COSTA RICA: EFFECTS OF CLIMATE, CLIMATE VARIABILITY AND CLIMATE CHANGE ON HUMAN HEALTH

The National Institute of Meteorology (IMN) and the Ministry of Health (MINSA), with the support of the United Nations Development Programme, carried out a study on the effects of climate, climate variability and climate change on human health in Costa Rica. The goal of the study was to characterize a group of diseases according to the sensitivity and exposure of the population (INM and Ministry of Health of Costa Rica, 2008). Thus, a relationship was established between climate, climate variability, climate change and the areas, regions or sectors most likely to suffer damages or losses.

To evaluate vulnerability to the prioritized diseases, quantitative methods were used to analyze sensitivity in order to establish a relationship between climate elements and historical records of rates or number of cases, and economic costs. Exposure to diseases was assessed through spatial identification of the area and population groups with greater disease incidence, and their relationship to climatic regions.

Four groups of diseases were identified using data available for different time periods: vector-borne diseases (Dengue, 1993-2006, Malaria, 2004-2006); cardiorespiratory diseases (asthma, 1998-2006, heart disease, 1990-2006); gastrointestinal diseases (diarrhoea, 1996-2006) and parasitic infections (abdominal angiostrongiliasis, 1995-1999). There are two groups that are most vulnerable to these diseases: vector-borne diseases such as dengue and malaria are most common in the economically active population between 15 and 45 years of age, while the other diseases present primarily in dependent persons, such as infants and the elderly. For this reason, the impacts on vulnerable groups affect national development since they cause absenteeism at school and work due to illness.

(continued)

Box 3 (Conclusion)

Climate, its variability and its change are not solely responsible for disease incidence, but they do explain a percentage that could be worsened by the effects of global warming. Future climate change scenarios predict an increase in extreme meteorological events that can be linked to the impacts of ENSO in Central America, and a 2°C to 6°C increase in temperature at the national level. Regarding dengue and malaria, the increase in temperature would affect the metabolism and physiology of mosquitoes (feeding rate, reproductive frequency), which could mean a greater risk of contracting these diseases in the entire country, especially in areas that are already high-risk. Regarding diarrhoea, a global increase of 1°C increases the number of cases of diarrhoea in developing countries by 5% (Cantero and Fonseca, 2007). However, above all, changes in rainfall will cause water imbalances that facilitate the propagation of viruses and bacteria that cause diarrhoea in children and adults (Cantero, 2007).

With regards to asthma, greater exposure to elevated environmental humidity and high temperatures could be harmful to the population. Finally, the estimated precipitation scenarios for the areas most affected by abdominal angiostrongyliasis could help decrease the risk of contagion in the population since the dry environment will limit the development of intermediate hosts for the parasite.

SUMMARY OF FEATURES OF VULNERABILITY

Disease	Exposure		Sensitivity	
	Vulnerable group	Vulnerable area (most vulnerable region and canton)	Correlation with climate change	Economic impact[a]
Dengue	Population group between 15 and 44 years. Economically active population	North Pacific and Caribbean region (Orotina)	Increase in environmental temperature and precipitation	$630 000 (¢346 million)
Malaria		Caribbean region (Matina)		$154 000 (¢85 million)
Asthma	Children under 9 years, adults over 65 years	Central Region, North Pacific and Central Pacific (Alajuela Centro)	Increase in environmental pollution, heat waves and humidity	$53 000 000 (¢29 billion)
Cardiovascular	Adults over 65 years with cardiac or respiratory deficiencies, hypertension and obesity	North Pacific, Central Pacific, and Central region (Atenas)	Increase in stratospheric ozone, in temperatures and heat waves	Data not available
Diarrhoea	Children under 5 years and adults over 65 years	Central region, North Pacific (San José Centro)	Water imbalances	$9 000 000 (¢5 billion)
Abdominal angiostrongyliasis	Children between 1 and 5 years, as well as the school-aged population	North area (Upala)	Water imbalances that affect the development of plagues of molluscs and rodents	$162 300 (¢89 million)

Source: IMN and Ministry of Health of Costa Rica, 2008.
[a] Annual average cost of healthcare for patients (dollars at current exchange rate of ¢550 per $1), based on average cost of visit, number of affected persons and the average number of visits per person.

The study identifies the valuable efforts made by countries of the region in estimating climate variability and its influence on human health. Some of these efforts involve the use of climate variables to explain the epidemiology of certain diseases, while others categorize these diseases by the time of the year (cold-heat, dry-rainy) to explain their seasonality. Despite the considerable volume and quality of published work, there is a strategic agenda yet to be covered in terms of establishing a relationship between temperature and precipitation and the incidence of key diseases, creating future climate change scenarios and their impact on human health in this region, and proposing intersectoral adaptation measures. The information available on climate-sensitive diseases in Central America makes apparent the following:

- The region has valuable experience in the research, treatment and prevention of tropical diseases, including vector-borne diseases. Dengue records, for example, show the existence of endemic areas with seasonal patterns, mainly in urban centers; however, studies relating this disease to climate variables are scarce.
- Malaria was a constant source of concern during the entire last century, especially during the construction of the Panama Canal. As shown in the health study of each country that is part of this technical series, the region has an active monitoring system for this disease. This has led to a low mortality rate and efficient medical attention during outbreaks in certain years. There is also a significant amount of information available on vector distribution and its link to environmental degradation.
- Chagas disease, on the other hand, is believed to be neglected in the region. Although there are local and international initiatives to control it, records are deficient and its association with chronic diseases is unknown. Despite the promotion of epidemiological research on this disease, the studies that link it to climate variables are scarce; existing studies are aimed at defining distribution, seasonality and vector habitat.
- The incidence of acute diarrhoeal diseases has a long history in the region. It is an illness associated with poverty that is concentrated in the infantile population. Although various studies try to understand the seasonal variations of this illness, there are no analyses that estimate changes under different temperature and precipitation scenarios.
- Food and nutritional security, stress and anxiety episodes, and skin conditions following hydro-meteorological events have received little attention; dehydration, heat strokes or stress, and various cardiorespiratory diseases related to atmospheric pollution and the increase in temperature in large cities have not been studied either.

This analysis confirms that several countries have begun studying climate and health: Guatemala, Nicaragua, Panama and El Salvador have focused on dengue; Belize y Panama, on malaria; and Guatemala y Belize, on Chagas disease. The research carried out in Costa Rica is particularly worth mentioning, as in addition to having appropriate health and meteorological information systems, its national communications report progress in the analysis of health as it relates to climate change.

According to the review that has been carried out, in order to advance the research on the impact of climate change on human health in Central America, it is advisable to:

- Promote a regional initiative to support research on climate change and health; this initiative can coordinate consolidated research teams in various disciplines and establish partnerships with different sectors.

- Analyse the implications of temperature, precipitation and the evolution of each country's demographic structure on studies of climate and health. In this sense, it would be ideal to consider future temperature and precipitation trends so as to predict health risks, and to incorporate ecological niche modeling to analyze the changes in species distribution due to climate change. This last aspect requires greater attention in the research of vector-borne diseases (VBDs).
- Not only evaluate the effects of climate change on the most vulnerable populations, but also analyze the establishment and spread of this vulnerability, so as to create specific proposals to help reduce it. Costa Rica and Panama have both made advances in assessing the problem and creating programs to address it.
- Carry out studies that include conditions of social and environmental vulnerability such as poverty, inequality, lack of access to health services, institutional response capacity and environmental degradation.
- Standardize approaches and methodologies in order to carry out valid comparisons and better understand the results.

- Recommendations for Disease analysis:
    - For vector-borne diseases like Chagas, leishmaniasis and climate-sensitive zoonoses, consolidate databases in order to carry out epidemiological studies related to climate at the regional and national levels, taking into account climate change scenarios and the geomorphologic and socioeconomic similarities between countries.
    - Given the importance of the cohort study of dengue in Nicaragua, expand and replicate it in other countries of the region in order to find causal associations between disease transmission and climate variables and social vulnerability.
    - Since it is known that diarrhoeal diseases are directly related to water quality, analyze their incidence following hydro-meteorological events.
    - Carry out studies on the adverse effects of air pollutants on the health of vulnerable groups such as children and the elderly in cities, and broaden the network of atmospheric monitoring stations.
    - Evaluate the impact of climate on agricultural production and food and nutritional security.

- Broaden studies on the impact of climate change in national communications, taking into account ecological, hydrological and agricultural regions as well as other relevant areas of analysis.
- Take into account conditions of social and environmental vulnerability that could alter biodiversity and ecosystems, as well as impact human health. These relationships are generally seldom studied.
- Treat the projections of climate change models and the different aspects of ENOS as tools to create regional policies on disease control. It will be necessary to carry out interdisciplinary studies involving research teams, health sector personnel and the community in order to develop adequate response measures.
- Strengthen systems for collection and analysis of epidemiological data. Researching the effects of climate change on health requires at least 30 years of retrospective data series, which is why the ability to carry out direct evaluations is limited and why climate models have to be used to estimate changes in climate and diseases.

- Use epidemiological methods that:
    - Limit the determining factors of the disease and the vulnerability of the population under study.
    - Describe the geographical area from which the health data comes.
    - Adequately assign meteorological data to the population of interest.
    - Include a plausible biological explanation that relates climate parameters to the disease.
    - Remove time trends and seasonal patterns in the time series analysis before assessing the possible link between climate and health.

It is important to point out that, besides the Ministries of Health and Environment, there are consolidated public sector research groups, such as the Gorgas Memorial Institute of Health Studies (ICGES) in Panama, the National Meteorological Institute (IMN) of Costa Rica and the university sector, especially in the field of vector-study. Likewise, international institutions such as the Mesoamerican Initiative for Public Health, the Institute of Meteorology (INSMET) of Cuba, the University of Miami and the University of Michigan, among others, have collaborated in important studies.

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