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VULNERABILITY AND RESILIENCE TO CLIMATE CHANGE IN WESTERN HONDURAS

JULY 2014

ARCC

African and Latin American
Resilience to Climate Change Project

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Cover Photo: Hillside maize production, Candelaria, Lempira. Photo by J. Parker, July 2012.

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AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

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ACRONYMS AND ABBREVIATIONS

ARCC	African and Latin American Resilience to Climate Change
CODEMS	Municipal Emergency Committees
CODELES	Local Emergency Committees
COPECO	Permanent Contingency Commission of Honduras
DGRH	*Dirección General de Recursos Hídricos*
ENSO	El Niño-Southern Oscillation
ERA	European Reanalysis
FAO	Food and Agriculture Organization
FIC	*Fundación para la Investigación del Clima*
FIPAH	Foundation for Participatory Farmer Research
FGDs	focus group discussions
FtF	Feed the Future
GHCN	Global Historical Climatology Network
HDI	Human Development Index
ICF	Institute of Forest Conservation
ICT	*Instituto Tecnologico Comunitario*
ICT	Information and communications technologies
IEH	*Instituto de Estudios del Hambre*
IFPRI	International Food Policy Research Institute
IHCAFE	*Instituto Hondureño del Café*
IRI	International Research Institute *for* Climate *and Society*
IPCC	Intergovernmental Panel on Climate Change
JAPOE	*Council for Administration of Water and Sewage Disposal*
KIIs	Key Informant Interviews
MEI	Multivariate ENSO Index
MODIS	Moderate Resolution Imaging Sectroradiometer
MPI	Multidimentional Poverty Index

NASA	National Aeronautics and Space Administration
NGO	Nongovernmental organization
PIF	*Programa de Investigación en Frijol*
PLCI	Permanent Land Cover Index
PY	psyllid yellow disease of potato
QSMAS	Quesungual Slash-and-Mulch Agroforestry System
RCPs	Recommended Concentration Pathyways
SES	social-ecological systems
TRMM	Tropical Rainfall Measuring Mission
WEIA	Women's Empowerment in Agriculture Index
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VA	Vulnerability Assessment
ZC	Zebra chip disease

EXECUTIVE SUMMARY

OBJECTIVES OF THE ASSESSMENT

The U.S. Agency for International Development (USAID)/African and Latin American Resilience to Climate Change (ARCC) Project conducted the Western Honduras Climate Change Vulnerability Assessment (Western Honduras VA) in 2014 in response to requests from USAID/Honduras. The assessment represents a multidisciplinary effort to assess the impact of climate change[1] and variability[2] on social and ecological systems in Western Honduras. This assessment focused on Western Honduras's Dry Corridor (in Spanish, *Corredor Seco*) region and the six departments receiving Feed the Future (FtF) programming support: Copán, Ocotepeque, Lempira, Santa Barbara, Intibucá, and La Paz.

The objectives of this assessment were to:

- understand the historical trends and future projections for climate in Western Honduras;
- assess how these climate projections will affect livelihoods and ecosystems in the region; and
- identify existing and potential adaptive responses that can be integrated into USAID, Government of Honduras, and other donor programming in Western Honduras to strengthen the resilience of livelihoods and ecosystems to climate-related impacts.

RESEARCH FRAMEWORK

The research framework for this assessment is based on the 2007 Intergovernmental Panel on Climate Change (IPCC) definition that vulnerability to the impacts of climate change is a function of exposure, sensitivity, and adaptive capacity. This assessment examines climate change vulnerability through the lens of social-ecological systems, which recognize the interaction and interdependence of humans and nature and the dependence of individuals and communities on ecosystem services for their livelihoods. Social systems refer to the individuals, households, communities, livelihoods, institutions, and networks that shape human society. Ecological systems refer to the resources that make up the natural environment, including land, water resources, forests, and watersheds.

The research team implemented this research framework through five distinct yet interconnected analytical components: climate; ecosystems (including eco-hydrology[3] and Protected Areas); phenology[4];

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[1] Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer) (IPCC, 2013).

[2] Climate variability refers to natural seasonal variations and multi-year cycles (for example, the El Niño-Southern Oscillation [ENSO]) that produce warm, cool, wet, or dry periods across different regions (IPCC, 2013). These events are part of natural variability and are not climate change.

[3] Eco-hydrology is an interdisciplinary field that studies the interactions between water and ecosystems (Zalewski et al. 1997). The three principles of eco-hydrology are: 1) hydrological (the quantification of the hydrological cycle of a basin); 2) ecological (the integrated processes at river basin scale that determine the basin's carrying capacity and ecosystem

value chains and livelihoods; and institutions. The assessment's analytical components have been woven together into an integrated assessment to generate evidence-based information on climate change vulnerability with the goal of informing USAID programming and investment decisions.

ASSESSMENT METHODS

The assessment employed a mixed-methods approach that used existing secondary and primary data collection through Key Informant Interviews (KIIs) with representatives of key national, regional, and local institutions as well as Focus Group Discussions (FGDs) with local institutions and farmers in Western Honduras. The research team adopted analytical methodologies and tools from the Southern Honduras Vulnerability Assessment where appropriate and also employed methodologies that have been used under previous climate change vulnerability assessments the ARCC Project conducted, including in Uganda, Malawi, and the Dominican Republic.

The **climate analysis** assesses temperature patterns, trends, and predictions; precipitation seasonality, trends, and predictions; and major climate disturbances in the region, including tropical cyclones and fire. High-resolution precipitation measurements of the satellite-borne Tropical Rainfall Measuring Mission (TRMM) radar, covering the period 1998-2013, are the basis for sub-regional comparisons and trend analyses. Department-level climatic characterizations were developed from quality-controlled Global Historical Climatological Network observations in a format provided by the World Bank and augmented by TRMM observations. National- and regional-scale temperature trends are taken from the authoritative, quality-controlled Berkeley Earth Project data series. Precipitation observations from the climatological station network of the *Dirección General de Recursos Hídricos* (DGRH) (seven stations) were used to validate TRMM observations covering the 1998-2013 period. Assessed climate predictions for temperature and precipitation are from consensus findings presented in the Fifth Assessment Report of the IPCC projections for the Central America region.

The **ecosystems analysis** assesses the sensitivity of ecological systems in Western Honduras to climate variability and change. This was carried out through two interconnected analyses: an eco-hydrology[5] analysis and Protected Areas analysis. The eco-hydrology analysis assesses land use cover as well as geomorphological and hydrological characteristics of eight sub-watersheds that represent the social and ecological characteristics of Western Honduras. An eco-hydrological vulnerability index is calculated for these sub-watersheds based on key eco-hydrological variables — permanent land cover and water production potential — in order to identify sub-watersheds with the greatest eco-hydrological sensitivity to exposure to climate projections of increased temperature and precipitation variability. The Protected Areas analysis assesses the current functioning of Protected Areas in the Western Honduras region based on a review of secondary literature, KIIs, and FGDs. Together these

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services); and 3) ecological engineering (the regulation of hydrological and ecological processes based on an integrative system approach).

[4] Phenology is the study of recurring biological phenomena and their relationship to weather, such as seasonal and interannual variations in climate. It is generally related to the effect of climate on the timing of biological events, such as the first emergence of buds and leaves, or date of harvest (Hermes, 2004).

[5] Eco-hydrology is an interdisciplinary field that studies the interactions between water and ecosystems (Zalewski et al. 1997). The three principles of eco-hydrology are: 1) hydrological (the quantification of the hydrological cycle of a basin); 2) ecological (the integrated processes at river basin scale that determine the basin's carrying capacity and ecosystem services); and 3) ecological engineering (the regulation of hydrological and ecological processes based on an integrative system approach).

analyses provide an in-depth understanding of the degree to which ecosystems in Western Honduras may be affected by climate-related stresses and shocks.

The **phenological analysis** focuses on major crops in the Western Honduras region — coffee; maize; beans; and two horticultural crops, potatoes and lettuce — to determine how projected changes in rainfall and temperature may affect the requirements for the growth cycle of each crop as well as associated diseases and pests. To determine the sensitivity of coffee, maize, beans, lettuce, and potatoes to climate change and variability, the phenological analysis took into account: 1) ranges of temperature and precipitation required for the development of each crop, specific to Western Honduras; 2) climate projections for Western Honduras based on the findings of the climate analysis; and 3) the potential impact on plant development under these projected climatic conditions at different phenological stages.

The sensitivity of social systems to climate change and variability was assessed through a value chain analysis and livelihoods analysis. Following the methodology utilized under ARCC's Uganda Climate Change Vulnerability Assessment, the **value chain analysis** used secondary literature, KIIs, and FGDs to assess the sensitivity of the selected value chains (coffee, maize, beans, and horticulture) to projected changes in climate and their impacts along the value chain. The **livelihoods analysis** is complementary and closely linked to the value chain analysis. It utilizes secondary literature and data generated from FGDs with farmers and local institutions to assess how climate variability and change directly and indirectly affect both agricultural and non-agricultural livelihoods. To expand upon the eco-hydrological vulnerability index, a social-ecological vulnerability index is calculated that integrates key social variables to identify sub-watersheds that are social-ecologically most sensitive to climate exposure.

An **institutional analysis** was woven throughout the specific component analyses as a means to understand sensitivity and adaptive capacity within these components. The institutional analysis, which utilized information generated from KIIs and FGDs with key environmental and agricultural institutions and farmers in the Western Honduras region, provided insights into the responses of regional and local institutions in Western Honduras for enabling adaptive responses to effectively withstand and respond to climate-related shocks and stresses.

Field research was carried out in two phases in this assessment: a **Scoping Trip** consisting of KIIs with key institutions, and a **Field Assessment Phase** consisting of FGDs with local institutions and farmers.

CLIMATE ANALYSIS RESULTS

After a rapid multi-decade increase in temperature peaking in 1998, the temperature trend in Western Honduras has been nearly neutral for the past 15 years, sustaining high baseline values above any experienced for many hundreds of years. Natural variability governs annual-decadal temperature trends in Western Honduras through the El Niño-Southern Oscillation (ENSO). The opposing phases of ENSO — El Niño and La Niña — typically cause monthly temperatures to be 0.75-1.0 °C above average and below average. Climate models predict increased temperatures of around +2 °C by 2050 due to greenhouse gas forcing. An absence of strong El Niño events since the late 1990s has suppressed the occurrence of exceptionally warm years; therefore, there is potential for an upward jump in baseline temperature mean with the return to an El Niño-dominated pattern of Pacific Ocean sea-surface temperatures.

The past 16 years have seen widely varying rainfall trends across the project region. Extremely large increases have occurred in the West, maximized around Ocotepeque (+35 mm/year trend); this increase is contrasted with the northern Santa Barbara region, where slight declines are observed. Rainfall trends currently show strong and sustained multi-decadal increases in all seasons; however, an analysis of frequency and intensity of rainfall reveals that the increase in precipitation may be due to more intense storm events rather than an increase in the actual number of days of precipitation. The

IPCC model consensus strongly asserts that significant drying on the magnitude of a 10-20 percent decrease in precipitation by 2050 will characterize the regional climate by mid-century. When taken with the model consensus of close to 2 °C of warming for the same time period, climate models suggest that by mid-century, Western Honduras may be a “hotspot” of magnified climate change stress as compared to other areas of Central America and Mexico. The potential for a shift to drier conditions makes it more urgent to take advantage of the current wetter-than-average climate to carry out adaptive actions such as reforestation of watersheds.

Tropical cyclones have been low frequency (one to two per decade) but high magnitude events (up to 50 percent of annual rainfall/five days) affecting Western Honduras. Risks may grow due to warming seas and also extension of hurricane season duration. Detailed climate model predictions of tropical cyclones are starting to become available but are inconclusive about how activity will evolve in the Central America region. The warming of sea-surface temperatures off both the southern and northern coasts will foster conditions more supportive for tropical cyclone development than in the past. Rainfall delivery in tropical cyclones is expected to increase by approximately 15 to 20 percent by late-century as the climate warms, suggesting increasing risks of high-magnitude flood events.

Satellite-based assessments of forest burning since 1996 suggest that precipitation trends and variability exert considerable control over fire occurrence. This result, inferred from national-level analysis, would need to be refined to the regional level to be quantified for Western Honduras.

POSSIBLE EFFECTS OF CLIMATE CHANGE ON ECOSYSTEMS

A 10 to 20 percent reduction in precipitation and an increase in temperature by between 1.0 and 2.5°C will have profound impacts on water resources in the region; this change will interact with and exacerbate other human-induced pressures affecting water quantity and quality, particularly where population growth rates and urbanization are high, such as in Santa Rosa de Copan, La Esperanza, Gracias, Ocotepeque, Marcala, and Santa Barbara. Possible effects of climate projections — including an increase in temperature by between 1.0 and 2.5 °C as well as a 10 to 20 percent reduction in precipitation — on water resources include: reduced surface water availability for direct use by communities and urban areas, agriculture, and economic processes; decreased groundwater recharge rates, which could substantially affect dry season flows; disappearance or reduced discharge rates of springs, which are an important water supply for rural communities in Western Honduras; increased use of irrigation upstream, leading to increased water competition and potential water conflicts among competing users; reduced soil moisture due to higher evaporation levels; and increased water pollution with potential impacts on human health and ecosystems.

The results of an eco-hydrological vulnerability analysis indicate that Venado-Lempa is the most eco-hydrologically sensitive to climate exposure, followed by San Juan-Lempa, Palagua-Goascoran, and Higuito. Venado-Lempa, San Juan-Lempa, and Palagua-Goascoran have the lowest water production potential of the selected sub-watersheds. Therefore, under climate projections of increased temperature and reduced precipitation, these sub-watersheds would face even greater conditions of water stress, as climate impacts would further reduce already scarce water supplies for ecosystems, crops, and human consumption. The least eco-hydrologically vulnerable sub-watershed based on these results is Grande de Otoro, which has the highest permanent land cover and highest water production potential rate of the eight selected sub-watersheds. Grande de Otoro’s high level of permanent land cover and high water production potential indicate that the sub-watershed has a greater ability to withstand the impacts of increased temperatures and reduced precipitation. However, the predicted climate scenario of a 1.0 to 2.5 °C increase in temperature and a 10 to 20 percent reduction in precipitation will result in significantly less water available within all sub-watersheds in the Western Honduras region; this reduction will create more stressful conditions for ecosystems, crops, livestock and communities.

The 21 Protected Areas of Western Honduras conserve more than 13 percent of natural vegetation in the region (i.e., permanent land cover). They play a critical role in building resilience to climate change and variability in the region by reducing vulnerability to floods, droughts, and other weather-induced problems; protecting people from sudden climate events; and supporting species to adapt to changing climate patterns by providing refuge and migration corridors.

Climate change predictions for the region will have significant impacts on natural ecosystems and Protected Areas in Western Honduras. Areas suitable for cooler, moister forest types — broadleaf forests, mixed forests, and pine forests — would decrease, and areas suitable for cloud forests would completely disappear. This change would have profound impacts on Protected Areas in Western Honduras. At least 15 Protected Areas in the region contain cloud forests, including Celaque, Opalaca, Montaña Verde, Puca, El Jilguero, Guajiquiro, Sabanetas, Montecillos, Mixcure, Volcán Pacayitas, El Pital, Montecristo Trifinio, Cerro Azul Copán, and Montaña de Santa Barbara. Climate impacts on cloud forests would, in turn, directly affect water supply for the thousands of communities in the Western Honduras region that depend on these Protected Areas and ecosystems for water resources. While areas suitable for cooler, moister conditions would significantly decrease, areas with climates suitable for shrublands and dry forests would increase.

POSSIBLE EFFECTS OF CLIMATE CHANGE ON CROPS

The targeted crops for this assessment — coffee, maize, beans, and two horticultural crops, lettuce and potatoes — were selected for analysis because they are those most widely grown in Western Honduras and are critically important for food and livelihood security in the region. The phenological analysis found that all crops are vulnerable to projected climate change impacts of increased temperature and reduced and more variable precipitation.

Coffee: Changes in the timing of rain and dry periods during floral development have significant impact on fruit and grain development. Arabica coffee responds sensitively to increasing temperatures, specifically during blossoming and fruit development. There is very high potential for increased prevalence of Coffee Leaf Rust, particularly under increased rainfall and warmer-than-normal temperature scenarios. Outbreaks tend to occur after periods of rain, as Leaf Rust requires water for spore germination.

Potato: The potato plant is susceptible to both drought and excessive water in the soil, and most vegetative stages are vulnerable to climate extremes. There is high potential for an increase in common pests and diseases that affect potatoes due to climate change impacts, particularly Potato Psyllid and Potato Late Blight. If not controlled by fungicide, Potato Late Blight can destroy entire potato fields in just a few days.

Lettuce: Excessive rain and drought will have an impact on early stages of the plant, in particular germination and early emergence, if seeds are germinated in fields. However, the use of raised beds and greenhouses to produce transplants is common practice in Western Honduras, and make lettuce less vulnerable to climate impacts in early stages of development.

Maize: Climate can affect maize at all stages of development, but the most vulnerable stages are at germination, flowering, and physiological maturity. Climate projections of increased precipitation variability and higher temperatures will affect early vegetative stages of germination as well as emergence and seedling growth. Extended dry periods are a serious problem for early maize plants and plants do not survive for very long if drought is associated with high temperatures. Climate projections of changes in the timing of precipitation patterns will likely force farmers to modify current planting and harvesting dates.

Beans: There is a moderate potential for decreased productivity of beans due to changes in precipitation, particularly during the vegetative stages of plant initiation and emergence. Under a scenario of low moisture in the soil, beans are comparatively more resilient than other crops and can tolerate mild droughts and also mild waterlogging due to additional rainfall. Excessive rain at the times of flowering can affect pod formation and reduce yield.

POSSIBLE EFFECTS OF CLIMATE CHANGE ON SOCIAL SYSTEMS

Livelihoods in Western Honduras are highly sensitive to climate impacts, as they depend predominantly on agriculture. A 10 to 20 percent reduction in precipitation and an increase in temperature by between 1.0 and 2.5 °C will have significant effects on livelihoods and agricultural value chains in Western Honduras. Taking this scenario into account, below we discuss potential direct and indirect impacts of these changes in climate on main livelihood systems and the targeted crop value chains.

Maize and beans. For basic grain production that occurs throughout the Western Honduras region, as climate impacts reduce yield of maize and beans, this reduction will create indirect effects on livelihoods through increased cereal prices, cost of feed, and increased prices of meat. This change, in turn, will decrease household consumption of cereals and reduce meat consumption. Reduced and rising local commodity prices would reduce all elements of household food security (access, availability, and utilization), which would negatively affect nutrition security for households, particularly for children. A situation of reduced household food security due to climate-related impacts could contribute to increased crime due to theft of crops. The impacts of the 2014 El Niño provide an indication of how climate-related shocks affect the maize and bean value chains in Western Honduras. Irregular and delayed rains have negatively affected maize and bean production in the region; this shift has significantly driven up prices, particularly for beans. In response, the government is importing beans through the National Commodity Supplier (BANASUPRO) in an attempt to stabilize prices. If these actions do not reduce hoarding behavior, the government is considering plans to freeze bean prices in local markets and supermarkets.

Coffee. Coffee is considered highly vulnerable to climate change and variability, both in terms of its phenological stages and the coffee value chain, thereby creating high levels of vulnerability for the many households in Western Honduras that depend on coffee production for their livelihoods. As climate change and variability affects quality and quantity of coffee, it will decrease household income for coffee producers, which in turn will reduce household food access (the affordability and allocation of food, as well as preferences of individuals and households). As many households that engage in the coffee sector work as wage laborers, the drop-off in demand would compromise the ability of these households to meet their food needs. The impacts of lower quality and quantity of coffee would have reverberations well beyond coffee producers and wage laborers, as they would affect employment and income generation across the many actors that make up the coffee value chain. These impacts would, in turn, negatively affect both the local and national economy of Honduras and reduce exports, thereby generating less revenue for the government. The complexity and scale of the coffee value chain means that climate shocks and stresses — both within and outside of Honduras — have the potential to produce significant impacts that reverberate across the value chain and affect all actors resulting in major impacts on the overall Honduran economy. For example, the impacts of Coffee Leaf Rust on coffee production in the 2012-2013 period resulted in economic losses totaling approximately $216 million. In 2014, poor households in Western Honduras have resorted to atypical, negative coping strategies as reduced coffee harvests and below-average *Primera* (May-August) staple grain production have limited their income and food stocks. Daily unskilled labor opportunities in Honduras are expected to decrease by between 16 and 32 percent compared to the 2011-2012 period due to the effects of the Coffee Leaf Rust. These events indicate how sensitive the coffee value chain is to climate-related shocks and the magnitude of impacts on livelihoods and the economy.

Horticulture. Increased temperatures and precipitation variability and extremes will decrease productivity of horticulture in Western Honduras. This trend, combined with the high irrigation demand of many horticultural crops, would likely reduce the large-scale viability of horticulture as a livelihoods diversification option across the region. Climate impacts on horticulture production will negatively affect employment in horticultural production regions of Western Honduras. As horticultural producers and wage laborers in Western Honduras are more prone to out-migration when employment options are limited, reduction of horticulture production due to climate change and variability could create a scenario of increased out-migration to urban areas and, in particular, to the United States.

CAPACITY TO ADAPT TO CLIMATE CHANGE AND VARIABILITY

Adaptive capacity can be defined as the ability of people and institutions to anticipate, withstand, and respond to climate change and variability as well as to minimize, cope with, and recover from climate-related impacts. Farmers in Western Honduras have implemented different adaptive practices to adjust to climate-related changes; however, the extent and pace of adoption and innovation does not match the scale of the challenge of climate change.

Local institutions — public, private, and civil society — play an important role in helping individuals and communities in Western Honduras withstand, adapt to, and respond to climate-related shocks and stresses. Some municipalities, particularly those where nongovernmental organizations (NGOs) and donor-funded projects have a strong presence, are more advanced in terms of implementing actions to address climate risk. In general, however, agriculture and environmental management institutions in Western Honduras have limited human, financial, and technical capacity to effectively implement measures to build resilience to climate change and variability. Local institutions in Western Honduras have implemented few actions that are specifically tailored to address climate vulnerabilities grounded in an evidence-based analysis of climate impacts. An institutional analysis of agricultural and environmental management institutions in Western Honduras revealed three significant institutional capacity gaps that hinder their ability to effectively build resilience to climate change impacts:

- ***Lack of local research and extension programs tailored to agro-ecological zones of the Dry Corridor.*** Few efforts in Western Honduras have focused on local agricultural and environmental research and extension that are tailored to the diverse agro-ecological zones of the region. Absent in the region are research and extension efforts focused on developing improved varieties of maize, beans, and coffee that are more heat-/drought-tolerant and adapted to the conditions of the dry corridor. In addition, few research and extension efforts target natural resources management in agriculture focusing on practices that will build resilience to climate-related shocks and stresses in the Dry Corridor.

- ***Inadequate information available for adaptive decision-making at local levels.*** Information and data are lacking for critical information needed to make decisions about climate change adaptation in Western Honduras, particularly information related to hydrology, soils, and land use. Our research found that where information exists, it is often concentrated at the national level and not shared or made available to decision-makers at the regional or municipal levels.

- ***Institutional focus on disaster response – insufficient emphasis on climate risk management and reduction.*** While national and regional institutions are making efforts to mainstream disaster risk management and reduction into overall development processes, this work has not yet translated into action at the local level in Western Honduras. Municipal Emergency Committees (CODEMS), Local Emergency Committees (CODELES), and activities implemented at the community-level continue to focus primarily on response after disasters take place rather than on actions that build community-based resilience to climate risk.

Policy and governance failures underlie threats facing Protected Areas and undermine their capacity to reduce vulnerability to climate change and vulnerability. Only seven of the 21 Protected Areas in the region have management plans. None of these existing management plans identify programs, strategies, actions, or activities related to climate change adaptation. The National Institute of Forest Conservation (ICF) does not have the required institutional presence in the field, nor do they have the financial resources to fulfill their constitutional commitment to manage or co-manage the region's Protected Areas. There is limited public awareness of the importance of Protected Areas and insufficient coordination among the actors and organizations that depend on the ecosystem benefits that these areas provide.

RECOMMENDATIONS AND ADAPTATION OPTIONS

Based on a review of the integrated findings on exposure, sensitivity, and adaptive capacity, a preliminary set of recommendations and adaptation options was developed along five adaptation pathways: 1) knowledge generation, management, and learning; 2) resilient water resources management; 3) conservation of critical ecosystems; 4) diversification; and 5) risk management. These five pathways provide an overarching and holistic strategy that integrates sustainable land and water management into production systems and landscapes as a means for building resilience of ecosystems and livelihoods in the Western Honduras region to climate change and variability.

- **Adaptation Pathway 1: Knowledge generation, management, and learning**. The VA revealed significant gaps in the generation of knowledge needed to make adaptive decisions to respond to climate change in the Dry Corridor, the management and coordination of that knowledge, and subsequent application and learning by decision-makers. We recommend the establishment of a "Climate Change Knowledge Center" for the Dry Corridor region that serves as a "one-stop-shop" for all data and research on climate change in the Dry Corridor. The Climate Change Knowledge Center would provide information on, and develop awareness about, climate change impacts and adaptation responses in the Dry Corridor with the objective of influencing decision-making for cross-sectoral adaptation efforts in the region. There is a strong need for participatory local research and extension efforts focusing on climate-smart water management practices and agricultural practices such as heat-/drought-tolerant varieties of maize, beans, and coffee, as well as soil, forestry, and agroforestry systems tailored to the diverse agro-ecological conditions in Western Honduras.
- **Adaptation Pathway 2: Resilient water resources management.** At its core, adaptation to climate change impacts in Western Honduras requires building the resilience of the region's water resources. To do this, decision-makers must have access to credible hydrological information to make management decisions in the face of an uncertain climate future. Efforts are needed to improve the evidence and information base on quantity and quality of water resources in Western Honduras as well as on-farm and watershed-level interventions that protect key water sources — particularly in upper recharge areas of sub-watersheds — and effectively build resilience to climate impacts on watersheds. Opportunities to establish payment for hydrological services schemes should be explored to create incentives for watershed management and water resources conservation. Activities should target sub-watersheds that are considered most vulnerable from an eco-hydrological standpoint; the eco-hydrology analysis identified El Venado-Lempa, San Juan-Lempa, Higuito, and Mocal-Lempa as most vulnerable.
- **Adaptation Pathway 3: Conservation of critical ecosystems.** Building the resilience of critical ecosystems in Western Honduras is essential for reducing vulnerability to climate change and variability, as these ecosystems are essential for providing and protecting key ecosystem services for communities in the region, particularly water supplies, and for regulating local climate and

hydrological flows. Actions should focus on protecting areas currently forested while restoring areas that have been cleared, particularly on steep slopes. Considerable effort is needed to improve the management of Protected Areas and buffer zones and to mainstream climate considerations into Protected Area management, as management institutions and plans currently do not take into account climate impacts. This work requires improved enforcement of current environmental laws and regulations that protect habitats, forests, watersheds, soils, and species.

- **Adaptation Pathway 4: Diversification.** Households in Western Honduras heavily depend on agricultural activities that are inherently vulnerable to climate change and variability. As the climate in Western Honduras becomes more variable in the future, agriculture as it is currently practiced is becoming a less viable livelihood option for rural families. Diversification, both within and outside of agriculture, is essential to buffer climate impacts and spread household financial risk. Considerable efforts are needed to identify, develop, and strengthen diversified on-farm and off-farm livelihood options that are more resilient to climate-related shocks and stresses. Climate-resilient on-farm options that should be explored include the production of cashews, mangoes, plums, timber, avocadoes, cocoa, sesames, and tamarind. Climate-resilient off-farm livelihood options could involve eco- or cultural tourism associated with Protected Areas, handicrafts, and the processing of agricultural and forestry products. The use of remittances and microcredit could facilitate off-farm livelihoods diversification and the development of rural microenterprises. Expanding and strengthening vocational education programs targeting youth will enhance on-farm and off-farm livelihood diversification.
- **Adaptation Pathway 5: Risk Management.** Local institutions in Western Honduras have focused principally on disaster response without sufficient understanding and attention placed on climate risk management and reduction. Efforts are needed at the municipal and community level in Western Honduras to build the capacity of local institutions, particularly CODEMS and CODELES, to reduce the risk of climate-related disasters. An important element of improving disaster risk management in Western Honduras is to strengthen the meteorological network and improve linkages between hydrometeorological information and early warning systems. Efforts are needed to increase the use of climate risk assessment tools and information available to local institutions at the municipal and community levels to integrate climate considerations into planning processes.

1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

The USAID/ARCC Project conducted the Western Honduras VA in 2014 in response to requests from USAID/Honduras. The objectives of this assessment are to:

- understand the historical trends and future projections for climate in Western Honduras;
- assess how these climate projections will affect livelihoods and ecosystems in the region; and
- identify existing and potential adaptive responses that can be integrated into USAID's programming in Western Honduras to strengthen the resilience of livelihoods and ecosystems to climate-related impacts.

The assessment represents a multidisciplinary effort to assess the impact of climate change[6] and variability[7] on social and ecological systems in Western Honduras. This assessment focused on Western Honduras's Dry Corridor (in Spanish, *Corredor Seco*) region and the six departments receiving Feed the Future (FtF) programming support: Copán, Ocotepeque, Lempira, Santa Barbara, Intibucá, and La Paz. Figure 1 depicts the study area for the assessment.

1.1.1 USAID's Climate Change and Development Strategy

The goal of USAID's 2012–2015 Climate Change and Development Strategy is to "enable countries to accelerate their transition to climate-resilient low emission sustainable economic development" (USAID, 2012, p. 1). The Strategy highlights the importance of natural resources management and biodiversity conservation as essential for building resilience of social and ecological systems to climate change and variability. The Strategy states that "Many years of leadership in biodiversity conservation and natural resources management inform climate sensitive approaches to land use planning and sustainable use of natural resources such as forests and water. Recognizing that this is an emerging field and that adaptation needs will vary considerably with local circumstances, USAID will support…. strengthening of environmental conservation actions that protect natural ecosystems on which human development depends" (USAID, 2012, pp. 16–17). One of the Climate Change and Development Strategy's "Guiding Principles" is to *value ecosystem services*. The Strategy recognizes that well-managed ecosystems provide important services, including food, water supply, erosion control, and flood protection, which are critical to maintain in order to reduce the impacts of climate change.

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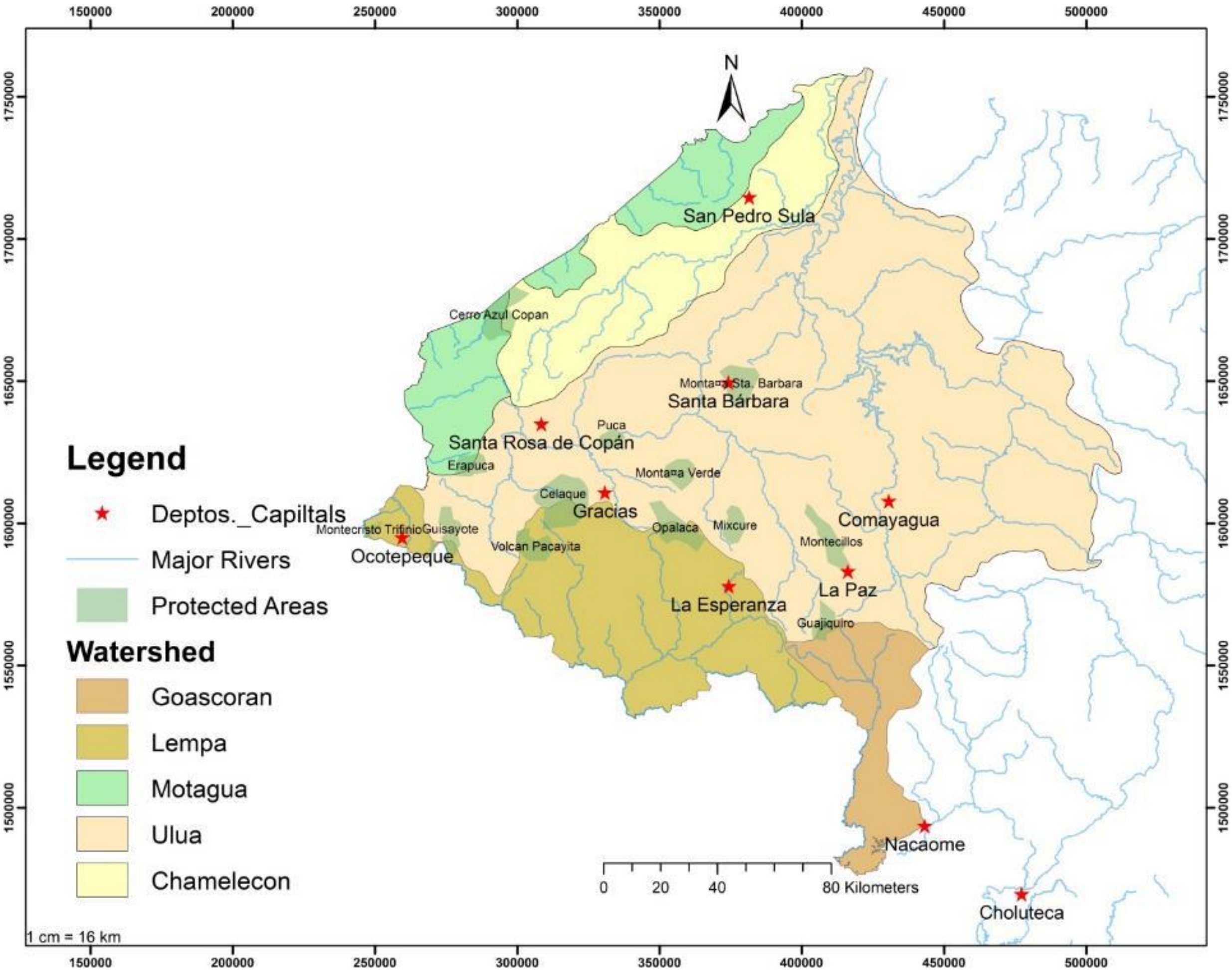
[6] Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer) (IPCC, 2013).

[7] Climate variability refers to natural seasonal variations and multi-year cycles (for example, the El Niño-Southern Oscillation [ENSO]) that produce warm, cool, wet, or dry periods across different regions (IPCC, 2013). These events are part of natural variability and are not climate change.

FIGURE 1. ASSESSMENT STUDY AREA



This assessment integrates historical climate data, projections of climate change, ecosystem sensitivity, phenological characteristics of key crops, and value chain and livelihoods linkages in a comprehensive way to construct an overall analysis of the social and ecological vulnerability to climate variability and change within the context of daily lives of households in Western Honduras.

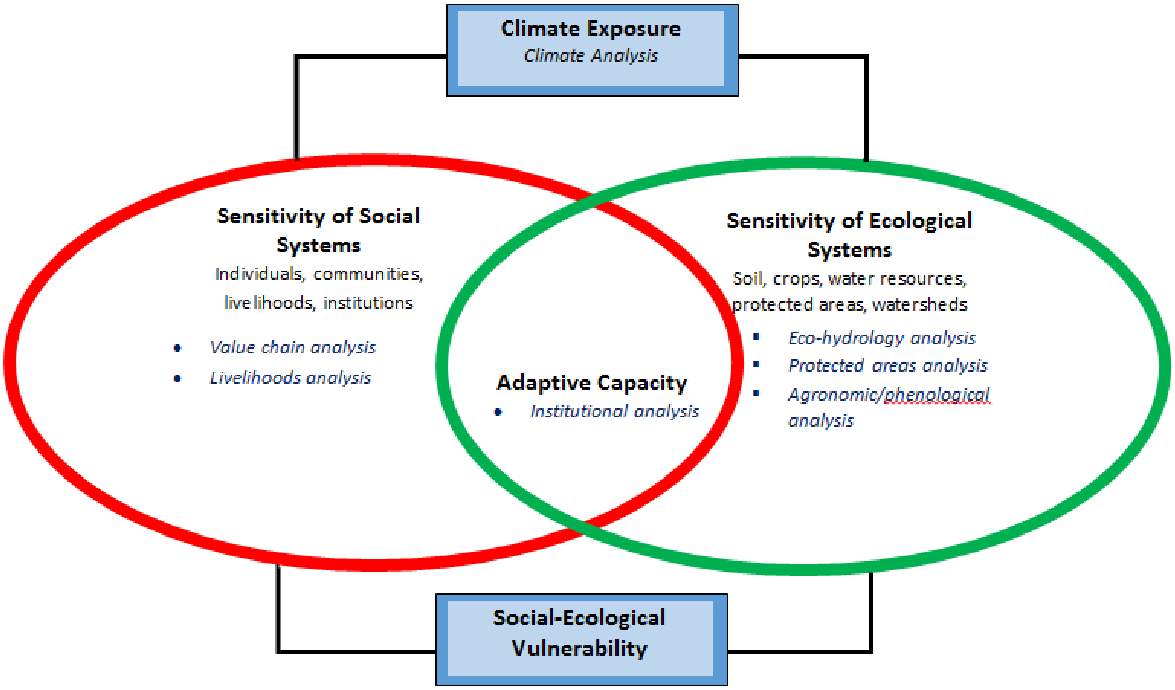
This report is organized into three sections. Section 1 (Introduction) presents the overall research framework, introduces the analytical components, and provides an overview of the assessment methodology. Section 2 presents the integrated assessment findings organized according to the key variables of vulnerability: exposure to climate change; sensitivity of ecosystems, crops, value chains, and livelihoods to climate change; and the adaptive capacity of households and institutions to respond to the projected impacts of climate change. Section 3 presents recommendations and adaptation options based on the comprehensive understanding of exposure, sensitivity, and adaptive capacity.

1.1.2 Research framework

The research framework for this assessment is based on the 2007 IPCC definition that vulnerability to the impacts of climate change is a function of exposure, sensitivity, and adaptive capacity (IPCC, 2007). Similar to the USAID/ARCC Southern Honduras Vulnerability Assessment, this assessment examines climate change vulnerability through the lens of social-ecological systems (SES). SES can be defined as integrated systems of ecosystems and human society with reciprocal feedback and interdependence (Resilience Alliance, 2007). Social systems refer to the individuals, households, communities, livelihoods, institutions, and networks that shape human society. Ecological systems refer to the resources that make up the natural environment, including land, water resources, forests, and watersheds. The concept of SES recognizes the interaction and interdependence of humans and nature and the dependence of individuals and communities on ecosystem services for their livelihoods (Füssel and Klein, 2006; Ostrom, 2009; Smit and Wandel, 2006; Turner et al., 2003; Walker et al., 2004) and has been applied as a framework for climate change vulnerability assessments in a wide range of contexts and regions worldwide (Fraser et al., 2011; Marshall et al., 2010).

The research team implemented this research framework through five distinct but interconnected analytical components: climate; ecosystems (including eco-hydrology and Protected Areas); phenology; value chains and livelihoods; and institutions. The assessment's analytical components have been woven together into an integrated assessment to generate evidence-based information on climate change vulnerability with the goal of informing USAID programming and investment decisions. Figure 2 below depicts how these analytical components fit within the social-ecological research framework.

FIGURE 2. SOCIAL-ECOLOGICAL RESEARCH FRAMEWORK FOR WESTERN HONDURAS ASSESSMENT



1.1.3 Assessment methodology

The assessment employed a mixed-methods approach that utilized existing secondary as well as primary data collection through KIIs and FGDs. The research team adopted analytical methodologies and tools from the Southern Honduras Vulnerability Assessment where appropriate. The research team also employed methodologies that have been used under other previous climate change vulnerability assessments conducted by the ARCC project, including in Uganda, Malawi, and the Dominican Republic.

The **climate analysis** provides a description of general climate characteristics of Western Honduras; temperature patterns, trends, and predictions; precipitation seasonality, trends, and predictions; and major climate disturbances in the region, including tropical cyclones and fire. It builds upon results previously developed in the Southern Honduras climate exposure analysis while shifting geographic focus and considering the more continental than near-coastal climatology. High-resolution precipitation measurements of the satellite-borne Tropical Rainfall Measuring Mission (TRMM) radar, covering the period 1998-2013, are the basis for sub-regional comparisons and trend analyses. Department-level climatic characterizations were developed from quality-controlled Global Historical Climatological Network observations in a format provided by the World Bank and augmented by TRMM observations. National- and regional-scale temperature trends are taken from the authoritative, quality-controlled Berkeley Earth Project data series. Precipitation observations from the climatological station network of the *Dirección General de Recursos Hídricos* (DGRH) (seven stations) were used to validate TRMM observations covering the period 1998–2013. Assessed climate predictions for temperature and precipitation are from consensus findings presented in the Fifth Assessment Report of the IPCC projections for the Central America region.

The **ecosystems analysis** assesses the sensitivity of ecological systems in Western Honduras to climate variability and change. This was carried out through two interconnected analyses: an eco-hydrology[8] analysis and Protected Areas analysis. The eco-hydrology analysis assesses land use cover, and geomorphological and hydrological characteristics of eight sub-watersheds. The selected sub-watersheds met the following four criteria: 1) they represent key recharge areas for Ríos Ulua, Lempa, and Goascoran and are therefore critical sources of water supply for the Western Honduras region; 2) they are located in the heart of the Dry Corridor, encompassing a representative range of livelihood zones and ecosystem types; 3) they provide key ecosystem services to important downstream population centers in the Western Honduras region; and 4) they have the potential to form an interconnected biodiversity corridor, both along watershed divides and along riparian areas that could enhance ecological resilience and biodiversity conservation in the region. Lessons from these sub-watersheds can be applied to other sub-watersheds in the Western Honduras region. An eco-hydrological vulnerability index is calculated for these sub-watersheds based on key eco-hydrological variables — Permanent Land Cover and water production potential — in order to identify sub-watersheds with the greatest eco-hydrological sensitivity to exposure to climate projections of increased temperature and precipitation variability. The Protected Areas analysis assesses the current functioning of Protected Areas in the Western Honduras region based on a review of secondary literature, KIIs, and FGDs. Together, these analyses provide an in-depth understanding of the degree to which ecosystems in Western Honduras may be affected by climate-related stresses and shocks.

The **phenological[9] analysis** focuses on the target crops for this assessment (coffee, maize, beans, and horticulture) to determine how projected changes in rainfall and temperature may affect the

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[8] Eco-hydrology is an interdisciplinary field that studies the interactions between water and ecosystems (Zalewski et al., 1997). The three principles of eco-hydrology are: 1) hydrological (the quantification of the hydrological cycle of a basin); 2) ecological (the integrated processes at river basin scale that determine the basin's carrying capacity and ecosystem services); and 3) ecological engineering (the regulation of hydrological and ecological processes based on an integrative system approach).

[9] Phenology is the study of recurring biological phenomena and their relationship to weather, such as seasonal and interannual variations in climate. It is generally related to the effect of climate on the timing of biological events, such as the first emergence of buds and leaves, or date of harvest (Hermes, 2004).

requirements necessary for the growth cycle of each crop as well as associated diseases and pests. Horticultural crops selected for the phenological analysis include potatoes and lettuce, which were identified in FGDs as those most commonly grown in the Western Honduras region. To determine the sensitivity of coffee, maize, beans, lettuce, and potatoes to climate change and variability, the phenological analysis took into account: 1) ranges of temperature and precipitation required for the development of each crop, specific to Western Honduras; 2) climate projections for Western Honduras based on the findings of the climate analysis; and 3) the potential impact on plant development under these projected climatic conditions at different phenological stages. The analysis involved a detailed examination of peer-reviewed literature and technical reports, supplemented by information gathered from KIIs and FGDs with farmers and institutions.

The sensitivity of social systems to climate change and variability was assessed through a value chains analysis and livelihoods analysis. Following the methodology utilized under ARCC's Uganda Climate Change Vulnerability Assessment, the **value chain analysis** used secondary literature, KIIs, and FGDs to assess the sensitivity of the selected value chains (coffee, maize, beans, and horticulture) to projected changes in climate and their impacts along the value chain. The **livelihoods analysis** is complementary and closely linked to the value chain analysis. It uses secondary literature and data generated from FGDs with farmers and local institutions to assess how climate variability and change directly and indirectly affect both agricultural and non-agricultural livelihoods. To expand upon the eco-hydrological vulnerability index, a social-ecological vulnerability index is calculated that integrates key social variables to identify sub-watersheds that are social-ecologically most sensitive to climate exposure.

An **institutional analysis** was woven throughout the specific component analyses as a means to understand sensitivity and adaptive capacity within these components. The institutional analysis, which used information generated from KIIs and FGDs with key environmental and agricultural institutions and farmers in the Western Honduras region, provided insights into the responses of regional and local institutions in Western Honduras for enabling adaptive responses to effectively withstand and respond to climate-related shocks and stresses.

Field research was carried out in two phases during this assessment: a **Scoping Trip** consisting of KIIs with key institutions, and a **Field Assessment Phase** consisting of FGDs with local institutions and farmers. During the Scoping Trip, the Assessment Team conducted KIIs with a wide range of institutions at national, regional, and local levels relevant to climate change, agriculture/food security, water resources, Protected Areas, and livelihoods in western Honduras. KIIs provided valuable qualitative data on the institutional context for climate change adaptation in the region, which informed the institutional analysis and enabled the Team to collect key secondary literature and data for their analytical components.

During the field assessment phase, the Team carried out FGDs in eight locations within five of the selected sub-watersheds (see Table 1). The selected FGD sites and sub-watersheds represent the social and ecological diversity of the six departments of Western Honduras. As previously discussed, they were selected based on four key criteria: 1) representative of key recharge areas for Ríos Ulua, Lempa, and Goascoran; 2) encompass a representative range of livelihood zones and ecosystem types in the Dry Corridor; 3) provide key ecosystem services for downstream population centers in the region; and 4) potential to form an interconnected biodiversity corridor, both along watershed divides and along riparian areas that could enhance ecological resilience and biodiversity conservation in the region.

TABLE 1. FOCUS GROUP DISCUSSION SITES AND CORRESPONDING SUB-WATERSHEDS

Focus Group Discussion Site	Sub-Watershed	Watershed
La Florida, Opatoro (La Paz) San Antonio del Norte (La Paz)	Palagua	Goascoran
La Esperanza (Intibucá)	El Venado	Lempa
Jesús de Otoro (Intibucá) Marcala (La Paz)	Río Grande de Otoro	Ulua
Tomalá (Lempira) Belén Gualcho (Ocotepeque)	Mocal	Lempa
San Marcos (Ocotepeque)	Higuito	Ulua

Two FGDs were conducted separately in each site: one FGD was composed of representatives of local institutions (municipalities, water associations, line ministries, women's groups, etc.); the other FGD included a group of farmers in each site who represented female and male farmers who received direct project assistance as well as those who had not received technical assistance.

FGDs with local institutions captured information on livelihoods, climate events, natural resources, and existing institutional capacity at the local level to withstand, respond, and recover from climate-related shocks. FGDs with farmers determined perceptions of changes in climate stress and corresponding adaptive responses. These FGDs helped explain and triangulate findings from the desk review and analytical components. Annex 1 presents the topical guides that were developed for each FGD to structure the discussions.

2.0 THE INTEGRATED ASSESSMENT FINDINGS

Vulnerability is defined as a function of three variables: exposure, sensitivity, and adaptive capacity. In this assessment, the following definitions are used for these variables:

- **Exposure** is defined as the nature and degree to which livelihoods and ecosystems in Western Honduras are exposed to significant climatic variations, such as alterations in the amount and distribution of rainfall, temperature, humidity, and the frequency and severity of extreme events, in addition to second-order impacts on disease and pest vectors as well as other biotic communities.
- **Sensitivity** is defined as the degree to which livelihoods and ecosystems are affected in Western Honduras by climate-related stresses and shocks. Sensitivity links elements of exposure to integrated social-ecological systems. For example, this assessment analyzes how climate change and variability can affect ecosystems, hydrology, crops, and crop value chains, as well as how these effects, in turn, can affect livelihoods in Western Honduras.
- **Adaptive capacity** is defined as the ability of people and institutions in Western Honduras to anticipate, withstand, and respond to climate change and variability, and to minimize, cope with, and recover from climate-related impacts. This assessment analyzes the adaptive capacity of farmers and local institutions to adjust to changes in the natural system.

The presentation of integrated findings begins with a description of exposure to climate change in Section 2.1. The report then describes sensitivity to climate change in Section 2.2, including an analysis of sensitivity of ecosystems, crops (coffee, maize, beans, and key horticultural crops), value chains, and livelihoods. Based on the results of these analyses, Section 2.3 (Adaptive Capacity) discusses how people and institutions in Western Honduras may withstand and adapt to the anticipated climate change impacts.

2.1 EXPOSURE TO CLIMATE CHANGE

2.1.1 General characteristics of climate in Western Honduras

In common with many areas in the tropical Americas, the annual climate cycle throughout Western Honduras has strongly defined seasonality, which is characterized by a prolonged wet season extending from May through October, a dry season with cooler overnight conditions from November through February, and hot and dry conditions in March and April. The mid-summer *canícula* period, characterized by reduced rainfall in July and August, is somewhat less pronounced than in other areas of the Central American isthmus. Occasional moist periods in the winter months are associated with cold frontal passages from the north.

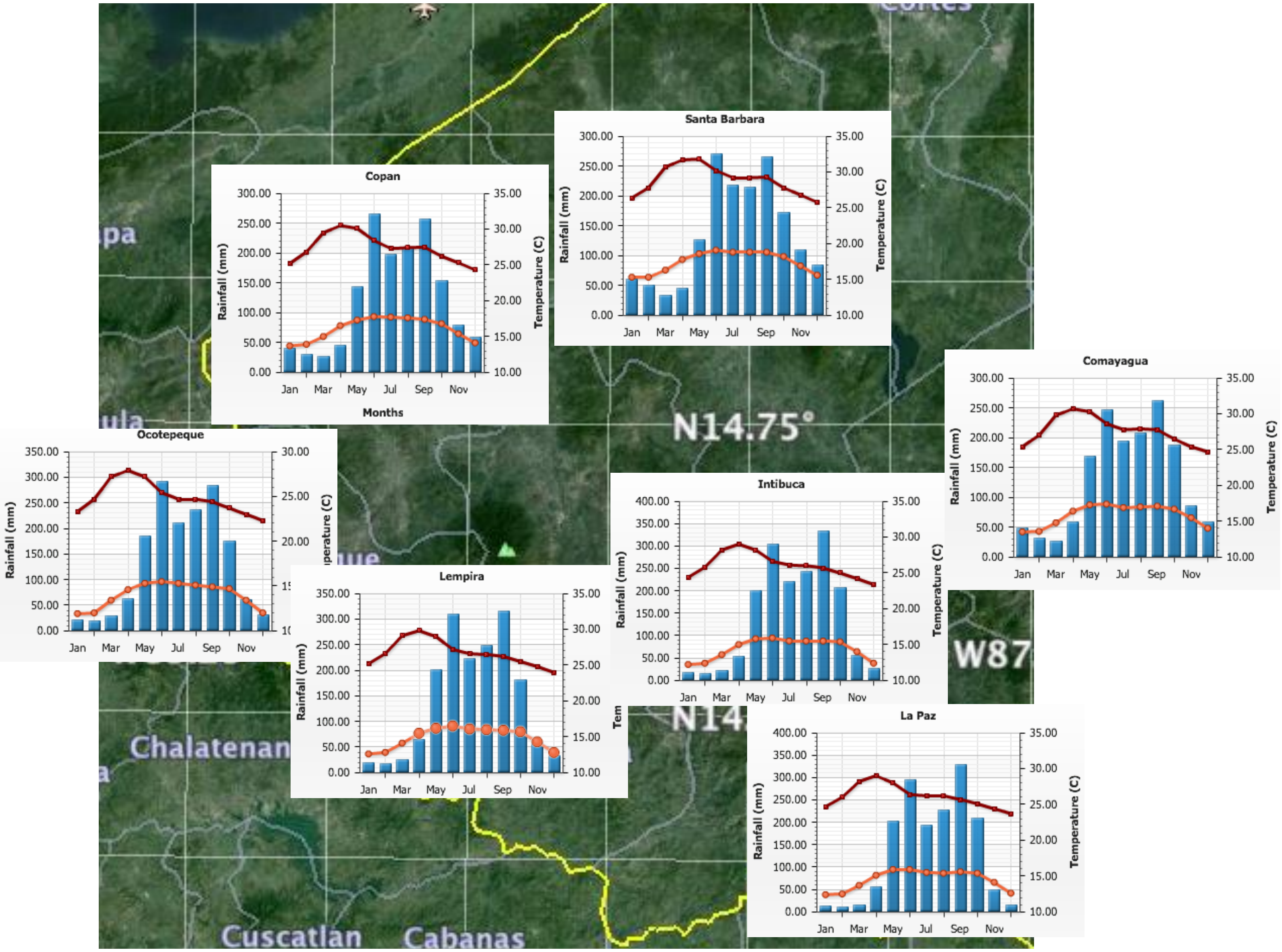
Figure 3 displays the annual climate cycle for different sub-regions of Western Honduras, which allows for comparison of seasonal temperature and precipitation cycles across the region. As Figure 3 demonstrates, the most significant sub-regional difference is higher rainfall during the winter dry season, most notably in December and January, in the region’s northern departments.

Characteristics common to all areas of Western Honduras include:

- marked alternation of wet and dry seasons of approximately equal duration;
- wet season bimodality with peaks in June and September;
- daily maximum temperatures peaking in April before wet season onset;
- significantly cooler conditions during the winter months; and
- warm and relatively invariant nocturnal temperature throughout the long wet season period.

The marked seasonality in rainfall is not matched by corresponding temperature changes of high magnitude. This trend is due to Western Honduras being within tropical latitudes, which limits incursions of cool air masses from the north as well as the moderating effects of Pacific Ocean and Caribbean coastal waters flanking the Central American isthmus.

FIGURE 3. CLIMAGRAMS PLOTTED ACCORDING TO APPROXIMATE GEOGRAPHIC PLACEMENT



Note: Annual cycles in maximum (red line) and minimum (orange line) temperature and precipitation totals (bar graph) at monthly resolution from weather stations in each department within west-central Honduras. Precipitation (mm/month, left axis on graphs) and temperature scales (°C, right axis) vary by location. Reproduced from World Bank (2013) based on climatological observations of the Global Historical Climatology Network (1998-2013).

Across Western Honduras, temperature varies spatially primarily as a function of elevation and local land cover, and to a lesser degree, proximity to the coast. In tropical regions, temperature decreases, on average 5-6 °C, for every 1000-meter increase in elevation (IPCC, 2013). Mountainous areas typically feature more extensive cloud cover than broad valleys and tend to be more forested; both of these factors suppress daytime maximum temperatures (IPCC, 2013). Figure 3 demonstrates that the hottest temperatures of the annual cycle occur in April prior to the rains. Significant rains occurring ahead of the main wet season onset introduce soil moisture and catalyze foliage growth after the long dry season; these factors act collectively to dampen daytime heating. An absence of rainfall events ahead of the wet season creates especially stressful conditions to most biota and livelihoods tied to agriculture, with unrelenting hot, desiccating days until the rains finally break (IPCC, 2013). The change from hot/dry to warm/wet conditions also creates a marked change in potential evaporation, reversing from strong hydrological losses to gains, promoting rapid greening of the landscape as the growing season begins.

Local temperatures are also affected by land surface type and land use history, because land use exerts strong controls over how incoming solar energy is absorbed. Deforestation, in particular, promotes greater heating of the land surface, causing higher daytime temperatures and drier conditions (IPCC, 2013). According to the Global Forest Resources Assessment (United Nations Food and Agriculture Organization [FAO], 2005), from 1990 to 2005, deforestation reduced forest cover in Honduras by approximately 37 percent (the fourth-largest percentage loss for any nation), which theoretically would significantly influence temperatures and dryness. A corollary effect of deforestation is an increase in the level of the cloud base; increased temperatures lower relative humidity, causing the bases of convective clouds to develop at higher altitudes (Ray et al., 2006). This effect occurs because deforestation promotes greater heating of the land surface and decreases evapotranspiration, thus increasing air temperatures and lowering humidity of the overlying air mass. This result is of major concern for the remaining cloud forest ecosystems in the project region, since the climatic conditions that support the cloud forest biome are effectively being elevated by anthropogenic changes. Even at lesser elevations, the occurrence of cool daytime mists in forests will diminish as the overall ecosystem becomes drier.

At sub-regional scales, the region's high terrain, prominent landforms, and multiple land surface types, both natural and anthropogenically modified, are instrumental in organizing meteorological circulations and moisture distribution on a daily basis. This complexity creates numerous microclimatic variations – mountains are invariably moister than valleys; north-facing windward slopes are more prone to receiving winter-time precipitation from cold frontal incursions, unforested valleys tend to have reduced cloud cover and higher daytime temperatures, and so on.

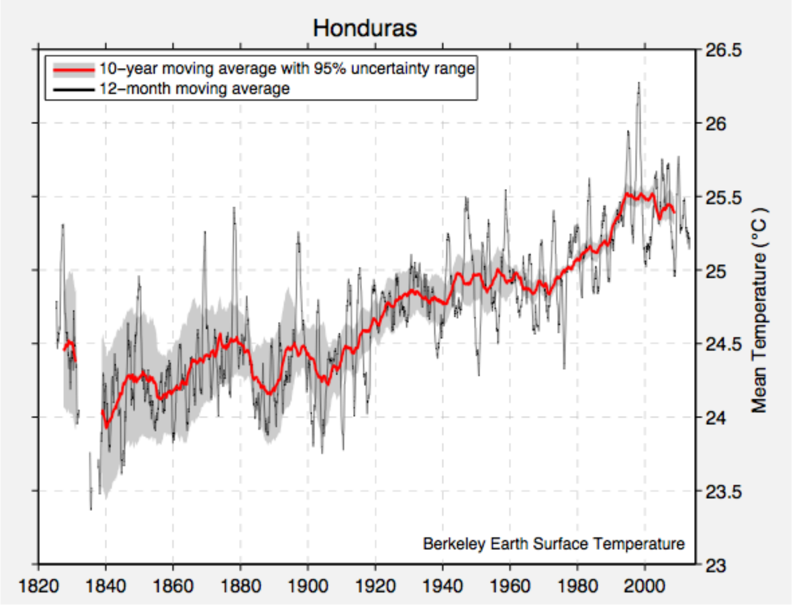
2.1.2 Temperature trends and predictions

Current temperature trends

In common with most landmasses worldwide, the Western Honduras region has experienced more than a century of warming that has leveled off, or even declined slightly, since a peak was reached in 1998. Several decades of climatological observations from weather stations in Western Honduras exhibit these patterns against a backdrop of considerable year-to-year variability.

Figure 4 displays national-level temperature trends for Honduras derived from Berkeley Earth[10], which depict a multidecadal rise over the latter part of the 20th century arrested by a slight reversal following the exceptionally warm El Niño event in 1998. It is expected that this is a temporary aberration and that rapid warming will resume in due course.

FIGURE 4. THE PAST 200 YEARS OF TEMPERATURE TRENDS FOR HONDURAS AS DEVELOPED BY THE BERKELEY EARTH PROJECT, BASED ON QUALITY CONTROLLED AND ADJUSTED STATION DATA



Source: Berkeley Earth Project, 2013

Time series data from two weather stations in Western Honduras — Copan and San Pedro Sula — demonstrate that the magnitude of interannual temperature anomalies, which can be up to 1.5 °C, is still somewhat larger than the magnitude of the baseline warming that has occurred since 1980 (about 0.90 °C). This interannual temperature variability is strongly associated with the alternation of El Niño and La Niña events, reflecting the tropical Pacific Ocean sea surface temperatures transfer of heat to the overlying atmosphere.

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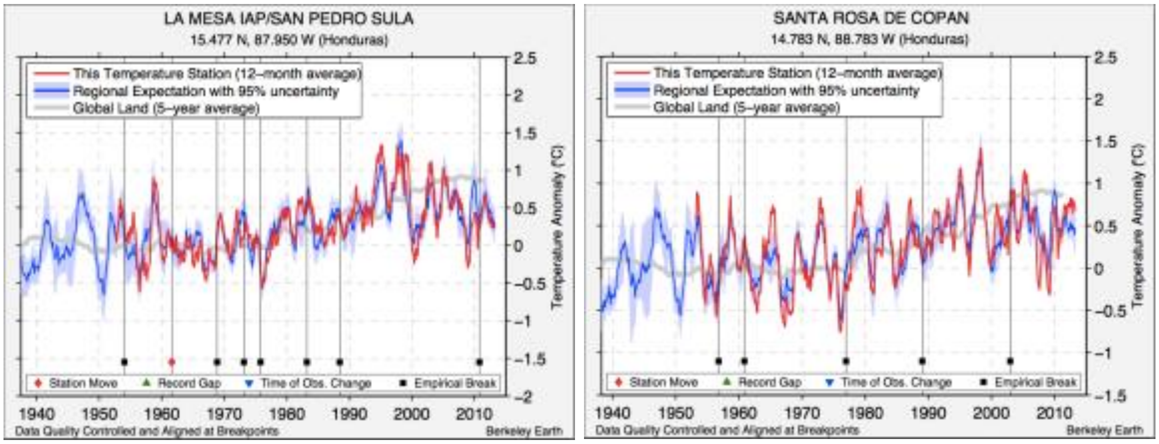
[10] The Berkeley Earth Project (www.berkeleyearth.org) offers an up-to-date, authoritative assessment of temperature trends as derived from quality-controlled and corrected climate station records, so its analysis products are used as the basis for the following discussions.

FIGURE 5. POST-1940 QUALITY-CONTROLLED AND ADJUSTED STATION DATA RECORDS FROM THE BERKELEY EARTH PROJECT FOR LA MESA/SAN PEDRO SULA (LEFT) AND SANTA ROSA DE COPAN (RIGHT).



Note: 12-month running mean temperatures, shown in red, can be compared to regional (blue) and global (gray) trends for corresponding periods. Source: Berkeley Earth Project, 2013

Berkeley Earth temperature data for Western Honduras, composited into a monthly temperature anomaly time series, correlate quite strongly with the Multivariate ENSO Index[11], as demonstrated by Figure 5. The close association between warmer and colder than normal temperature and El Niño and La Niña events across western Honduras identifies that regional ecosystems have longstanding exposure to interannual as well as inter-seasonal variations in temperature. The century-long warming trend, as depicted in the previous figures, means that the coolest years of the past decade are comparable to the warmest years experienced just 75-100 years ago.

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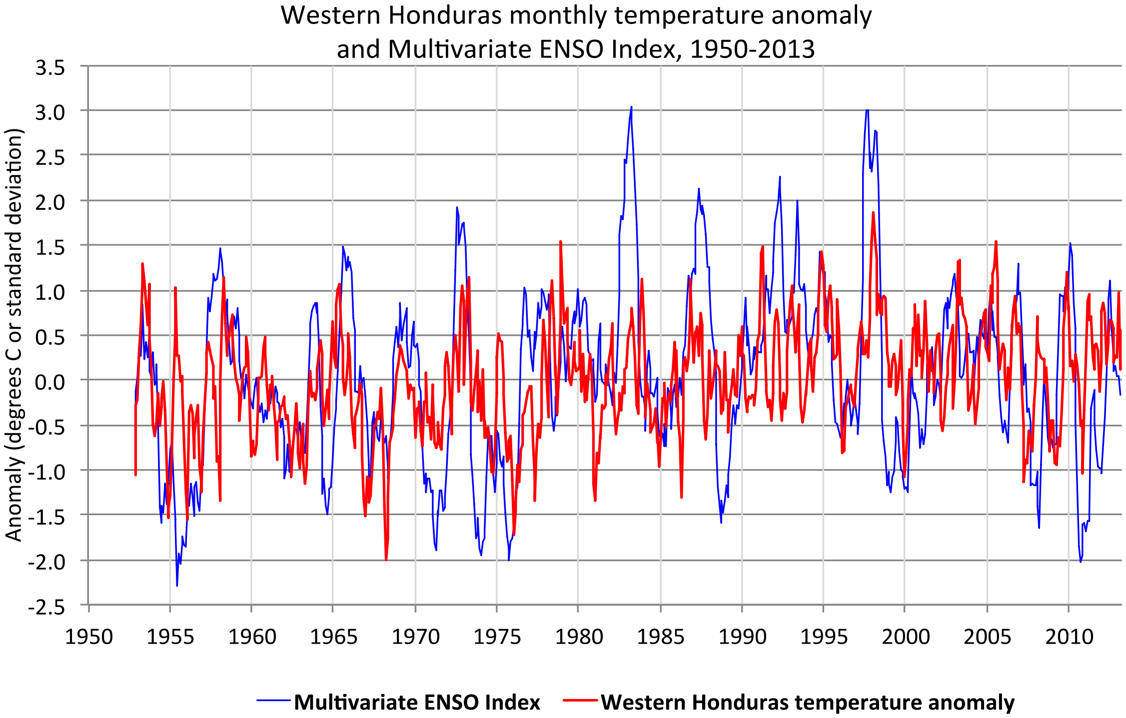
[11] The Multivariate ENSO Index (MEI) is a diagnostic tool used to characterize the combined atmosphere-ocean response to ENSO Variability. Readers can learn more at their website at: http://www.esrl.noaa.gov/psd/enso/mei/

FIGURE 6. TIME SERIES OF WESTERN HONDURAS TEMPERATURE DEPARTURE FROM MONTHLY MEANS (IN °C, RED) AND MULTIVARIATE ENSO INDEX (MEI, IN STANDARD DEVIATIONS, BLUE)

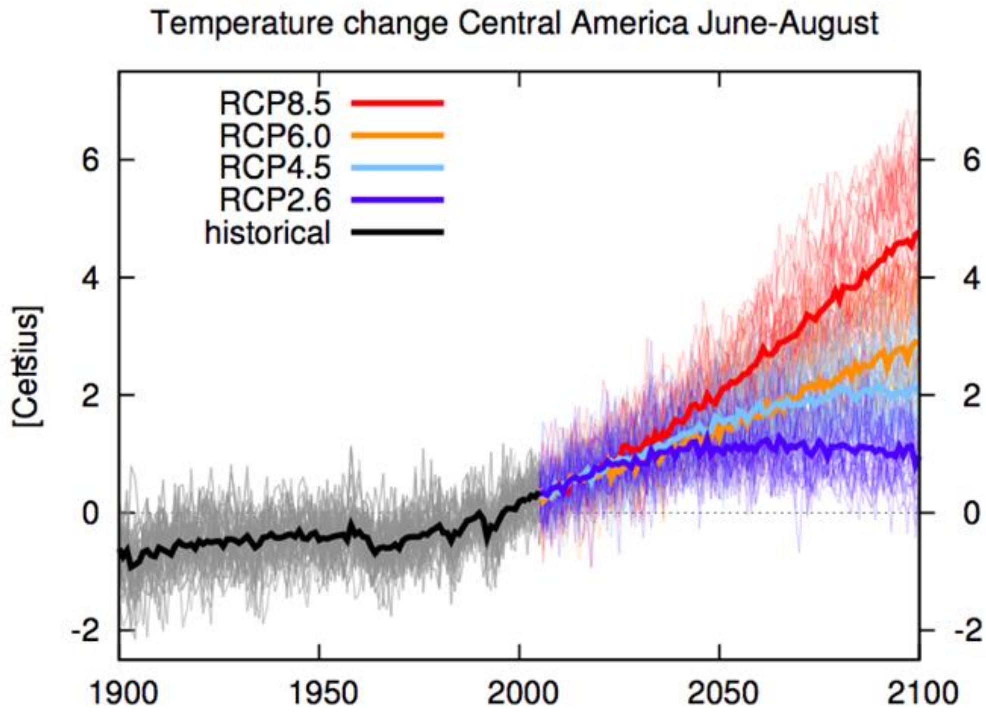


Note: Correlation maximizes at R=0.60 when temperature lags the MEI value by one to two months. Sources: for temperature data, Berkeley Earth project, 2013; for MEI, National Oceanic and Atmospheric Administration (NOAA), 2014.

Temperature predictions for Western Honduras

Under intensifying greenhouse gas concentrations, climate models predict that the current multidecadal warming trend for Western Honduras will continue (IPCC, 2013; *Fundación para la Investigación del Clima* [FIC]/*Instituto de Estudios del Hambre* [IEH], 2013). Figure 7 demonstrates that temperature over the Central American landmass, including Western Honduras, is projected to increase by between 1.0 and 2.5 °C by mid-century under all four emissions levels assessed in the modeling studies (IPCC, 2013). This situation underlies an important assertion for long-term planning in Western Honduras: **Continued warming is a near certainty through at least 2050 and will continue to bring temperatures ever higher**. This trend will occur regardless of whether major reductions in greenhouse gas emissions occur or not. Even the most optimistic scenario (Recommended Concentration Pathway [RCP] 2.6), which calls for declining greenhouse gas concentrations, matches this pattern.

FIGURE 7. TIME SERIES OF TEMPERATURE CHANGE RELATIVE TO THE 1986-2005 PERIOD AVERAGED OVER LAND GRID POINTS IN CENTRAL AMERICA FOR JUNE-AUGUST UNDER FOUR DIFFERENT RCPS



Note: RCPs are the different global emissions trajectories that the IPCC utilizes. Thin lines denote model simulations; thick lines the multi-modal mean. Source: Reproduced from Figure A1.25 in IPCC (2013) Working Group 1, Annex 1.

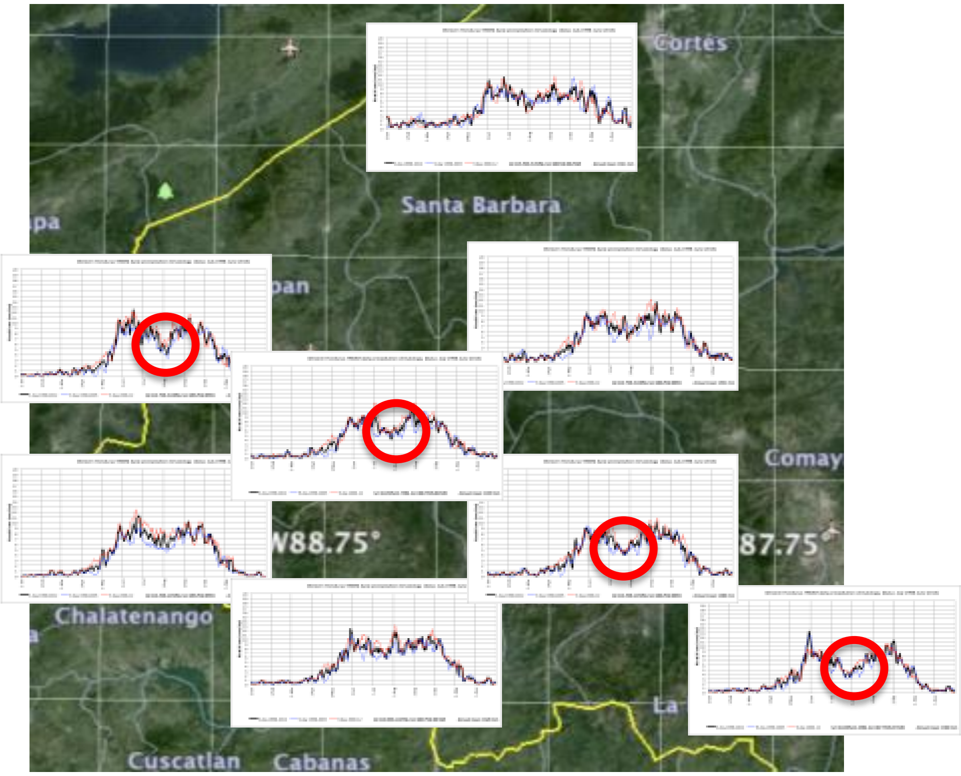
2.1.3 Precipitation trends and predictions

The spatial variability of rainfall across western Honduras is organized around the dry corridor, a broad axis running locally along the interior of the Central American Isthmus, where annual rainfall is significantly lower than more coastal areas to both the North and the South. Figure 8 demonstrates spatial differences in annual mean rainfall across the Western Honduras region based on rain gauge and satellite-borne radar observations over the 1998-2013 period. Most rainfall totals in Western Honduras range between 1350 and 1650 mm. Wetter climates are found both to the North and the South; the dry corridor is characterized by increased dryness along the corridor's axis trending from west to east.

FIGURE 8. SPATIAL DIFFERENCES IN ANNUAL MEAN RAINFALL ACROSS THE WESTERN HONDURAS REGION

Figure 9, on the following page, displays the annual precipitation cycle and trends across space, which reveals sub-regional differences in characteristics of rainfall across the Western Honduras region. Red circles highlight the mid-year *canícula* at sites along the dry corridor, where significant reductions in rainfall rate are experienced, as compared to areas both the North and the South. As Figure 9 demonstrates, the *canícula* is most evident along the dry corridor axis.

FIGURE 9. SPATIOTEMPORAL CHARACTERISTICS OF RAINFALL ACROSS THE WESTERN HONDURAS REGION



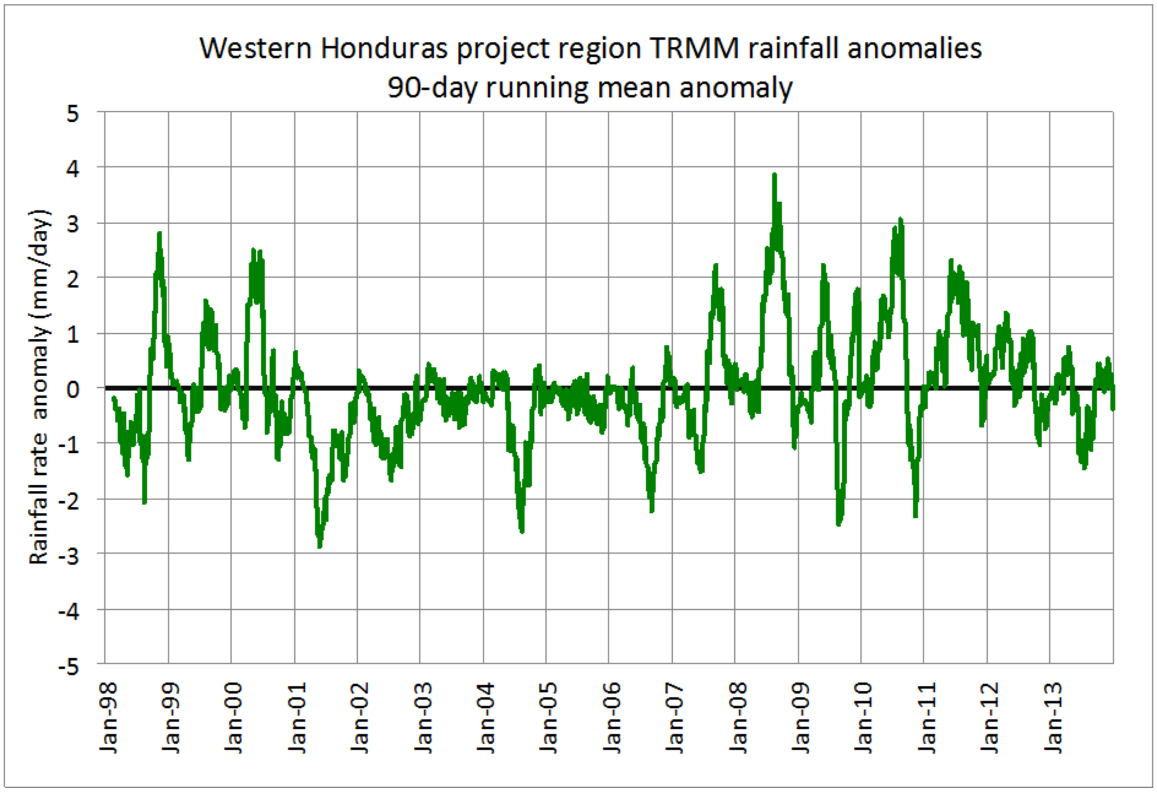
Note: Pluviograms for selected TRMM pixels (background grid, 27x27 km spatial dimensions) displayed according to their geographic distribution reveal sub-regional differences in spatiotemporal characteristics of rainfall across the Western Honduras region. Red circles highlight the mid-year canícula.

Rainfall anomalies associated with droughts and floods

Rainfall anomalies — positive or negative departures from precipitation means — normally develop and last from weeks to months in duration and create stressful conditions of flood and drought. In Western Honduras, floods and droughts tend to be expressions of external factors, such as ENSO to the South in the tropical Pacific and jet stream behavior much further to the North over North America.

The regional TRMM dataset, plotted as a time series of rainfall departures from daily climatological means, offers a detailed portrayal of droughts as well as unseasonably wet and potentially flood-causing conditions for the 1998-2013 period (Figure 10, following page). Both drought and flood episodes have occurred repeatedly during this period, most notably 2001, 2004, 2009, and 2010 for droughts, and 1998, 2000, 2008, and 2010 for rainfall excess. The major El Niño year of 1998 was, in fact, characterized by below-normal rainfall until the deluges of Hurricane Mitch created an abrupt transition from drought to the most severe flood on record. In contrast, the wet season of 2010 was among the wettest on record but ended prematurely, creating a flood-to-drought transition in rapid succession.

FIGURE 10. DAILY RAINFALL RATE ANOMALIES (MM PER DAY)



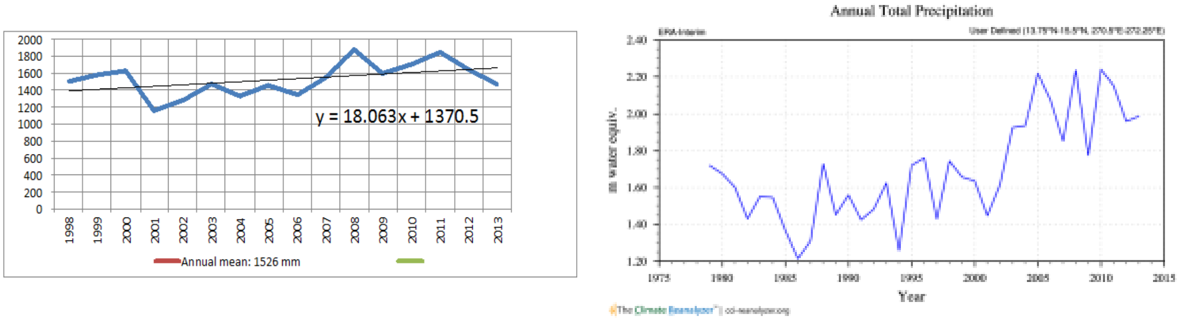
Note: Daily rainfall rate anomalies (mm per day) are assessed relative to the climatological daily means in TRMM data aggregated for the Western Honduras project region for the 1998-2013 period. Data are presented as 90-day running means to smooth out short period variations.

A perception participants of FGDs commonly identified during the field assessment phase — that rainfall is less reliable at present than in the past — finds support in these observations, too. The 2001-2006 period featured four significant dry spells or droughts, with no compensating positive anomalies. Since 2007, however, rapid alternation of excessive wetness and dryness has yielded a highly unstable climatic regime that must have been particularly stressful to rain-fed agriculture and other water-dependent activities.

Rainfall trends

Observational data offer strong indications that seasonal rainfall regimes are changing extremely rapidly over most of Western Honduras, with a marked trend towards wetter conditions. The factors underlying this behavior remain to be determined, although both external factors, including atmospheric circulation changes arising from natural variability and/or anthropogenic impacts at broad scales, as well as land surface changes at more local scales, may be acting individually or in concert. Figure 11 depicts TRMM observations for 1998-2013, which indicate a well-defined increase in precipitation across Western Honduras averaging +18 mm/year. A longer perspective extending back to 1979 (Figure 11, right), based upon rain gauge and global model interpolation of multiple atmospheric parameters, identifies that the recent trend in increased annual precipitation across the region is an acceleration of an upward trend that first became apparent in the mid-1990s (Figure 11).

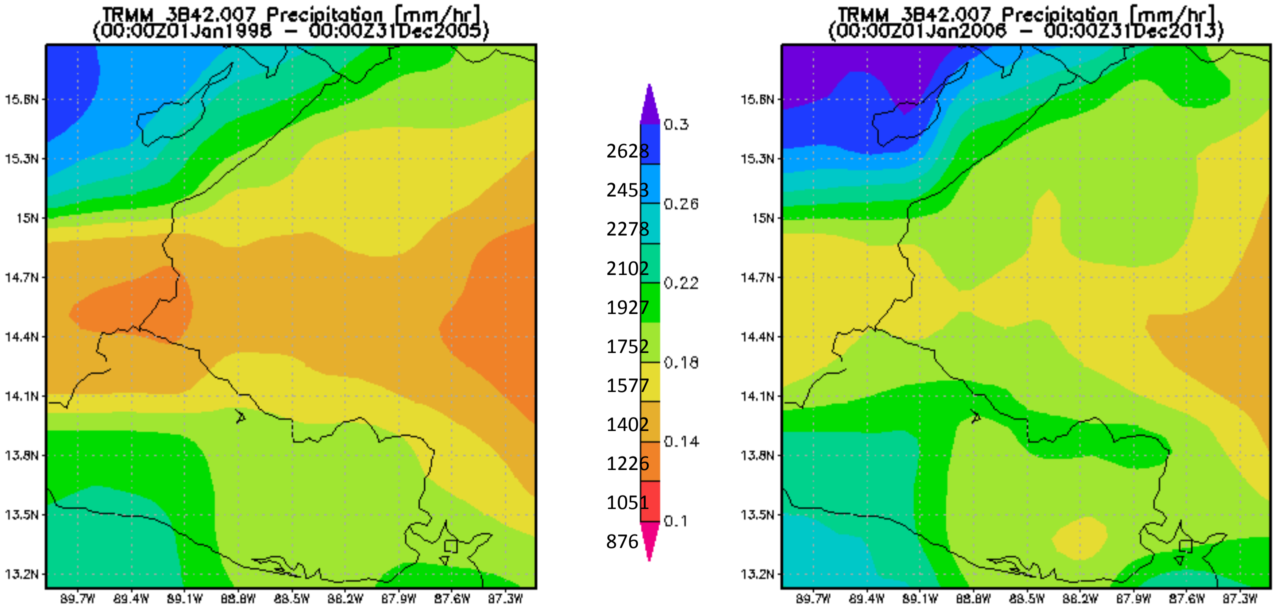
FIGURE 11. ANNUAL PRECIPITATION TRENDS FOR WESTERN HONDURAS



Note: Left image depicts TRMM measurement aggregated for the Western Honduras region from 1998-2013; right image depicts regional rainfall for 1979-2013 as developed by the European Reanalysis (ERA)-Interim global atmospheric reanalysis, produced by European Centre for Medium Range Weather Forecasts. The regression line on the left panel shows that rainfall has increased at a mean rate of 18 mm per year during the period of TRMM observations. Sources: (left) National Aeronautics and Space Administration (NASA) TRMM data; (right) image obtained using Climate Reanalyzer, Climate Change Institute, 2014.

Figure 12 further analyzes the trend of increased precipitation in Western Honduras by characterizing how increased precipitation has been experienced geographically across the region. The geographic distribution of rainfall maintains the dry corridor axis around latitude 14.5 deg. N, yet the rainfall rate increases markedly, maximized around the tri-national border region.

FIGURE 12. TRMM ANNUAL MEAN RAINFALL FOR 1998-2005 (LEFT) AND 2006-2013 (RIGHT) OVER WESTERN HONDURAS AND ADJACENT EL SALVADOR AND GUATEMALA

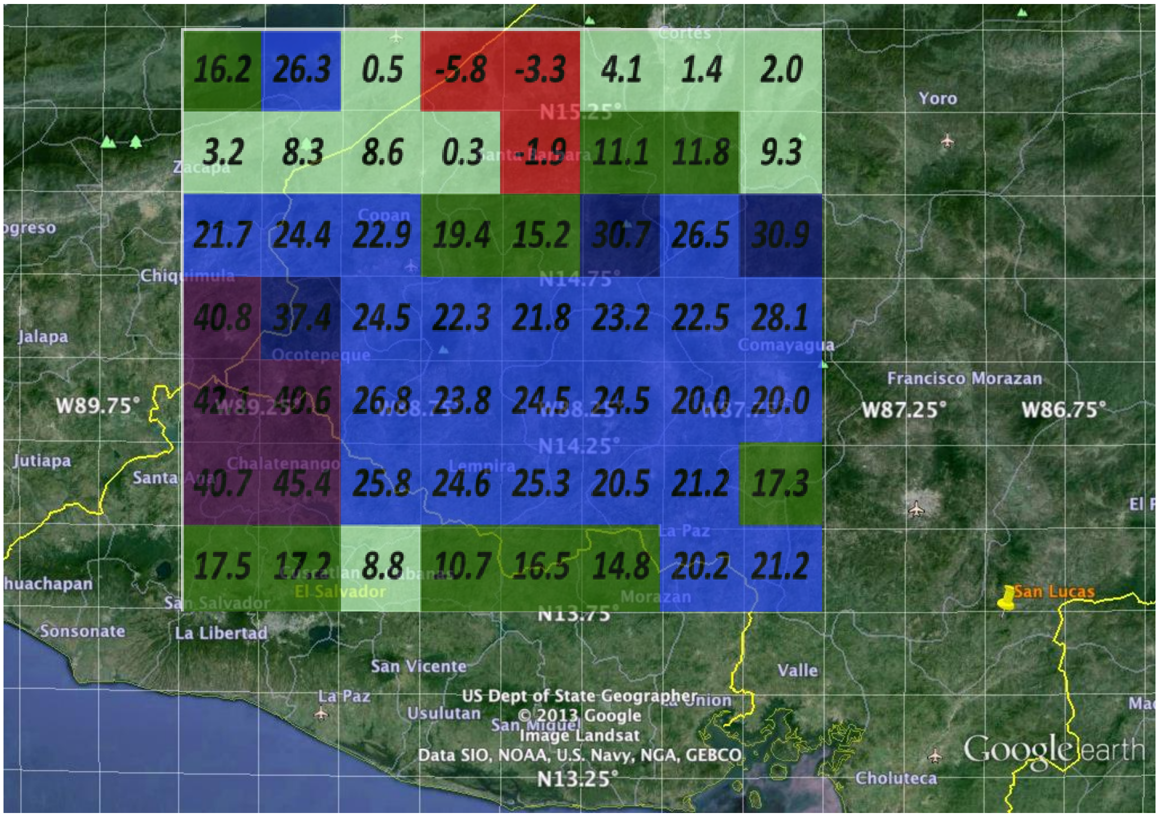


Note: Rainfall rate is shown in mm per hour; multiply by 24 to convert to mm per day.

The percentage change in rainfall over the TRMM observational period is mapped spatially in Figure 13. The most significant changes are extraordinarily large increases registered in the area centered over

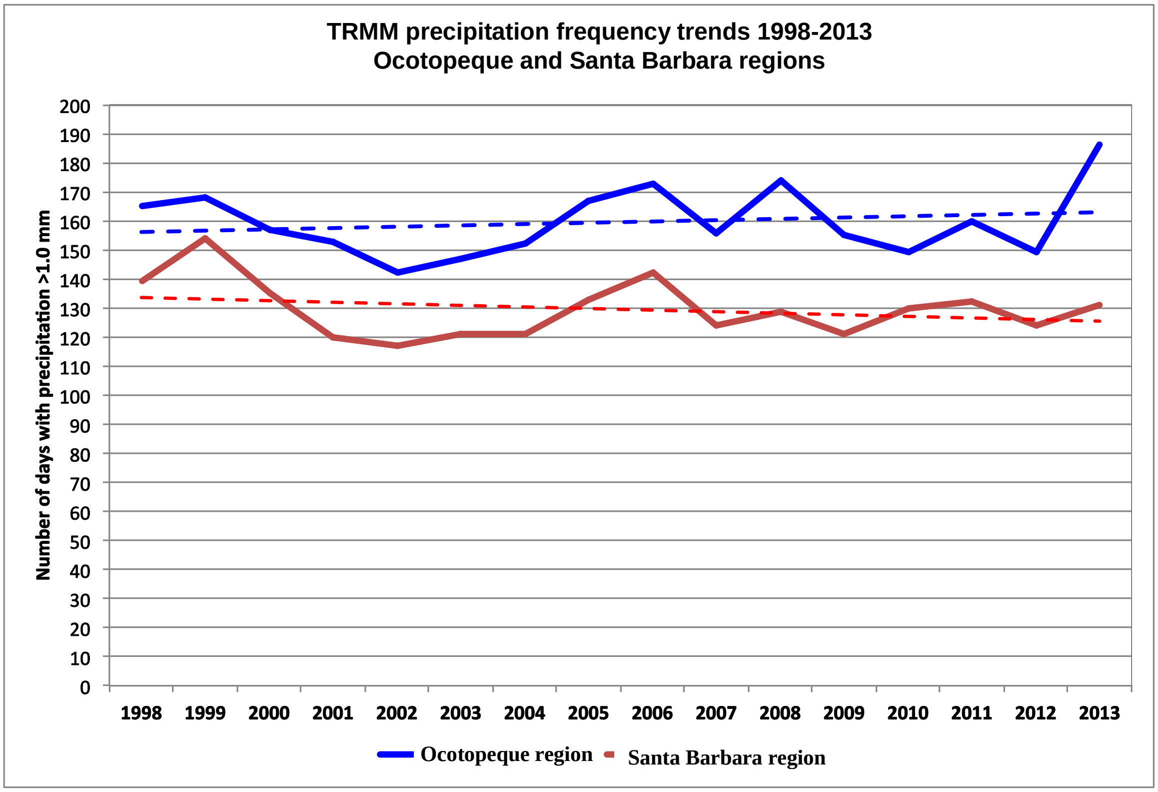
Ocotepeque and nearby parts of El Salvador and Guatemala. Rainfall here, which averaged around 1100 mm in the late 1990s, now averages close to 1650 mm, increasing by 35 mm per year on average. In contrast, less than 150 km to the northeast, rainfall over northern Santa Barbara exhibits a slight negative trend. These findings suggest that regional ecology, hydrology, and human activities likely exist in a state of dynamic flux as they respond to rapidly shifting hydrological baseline conditions – especially so in the southwestern part of the project region, where changes are greatest.

FIGURE 13. MAGNITUDE OF CHANGE IN RAINFALL (%) BETWEEN 1998 AND 2013 DEVELOPED REGRESSION STATISTICS FOR EACH 27X27 KM TRMM PIXEL WITH GRID CELLS COLORIZED ACCORDING TO MAGNITUDE IN 10-PERCENT INCREMENTS



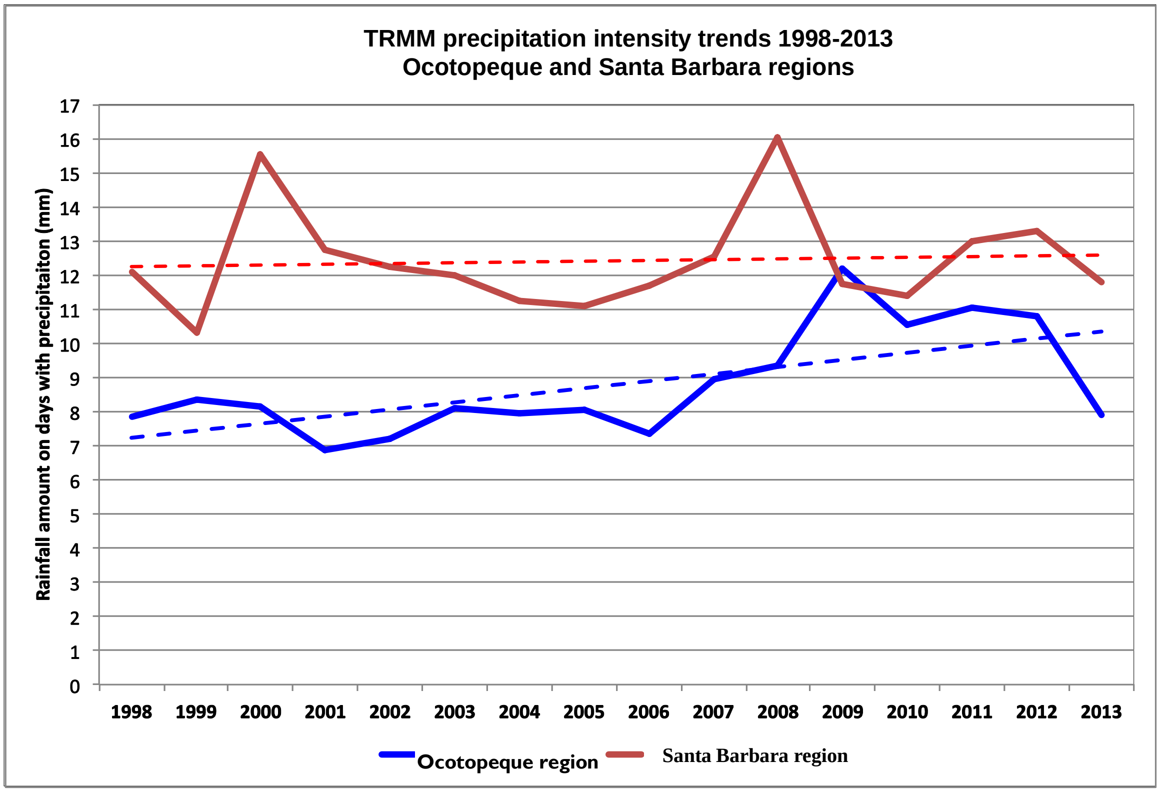
However, an analysis of frequency and intensity of rainfall reveals that the increase in precipitation across Western Honduras may be due to more intense storms and precipitation events rather than an increase in the actual number of days of precipitation. This finding could partly explain perceptions from farmers that they are experiencing drier conditions, but that when it does rain, precipitation events are more extreme. In the far-western region around Ocotepeque, where there has been a 40-percent increase in rainfall amount since the late 1990s, the number of days with rain increased only slightly (Figure 14), but the rainfall amount on the days in which rainfall occurs shows a strong trend of increase (Figure 15). During the 16-year period of satellite observations, this increase totals 3.2 mm of addition rainfall per day with precipitation. These observations identify a rapid intensification in rainfall rate in this part of Western Honduras. This result contrasts with TRMM measurements for northern Santa Barbara near San Pedro Sula, where annual rainfall has declined slightly during the 16-year period. In this area, the average rainfall amount on days with precipitation shows a very slight increase of 0.5 mm over 16 years (see Figs. 14 and 15).

FIGURE 14. NUMBER OF DAYS PER ANNUM WITH PRECIPITATION ≥ 1.0 MM IN TRMM SATELLITE RAINFALL OBSERVATIONS 1998-2013 FOR THE OCOTEPEQUE REGION (BLUE) AND SANTA BARBARA REGION (RED)



Note: Annual counts are shown by solid lines. Trends from linear regression are dashed lines.

FIGURE 15. ANNUAL AVERAGE RAINFALL AMOUNT (MM) ON DAYS WITH PRECIPITATION ≥ 1.0 MM IN TRMM SATELLITE RAINFALL OBSERVATIONS 1998-2013 FOR THE OCOTEPEQUE REGION (BLUE) AND SANTA BARBARA REGION (RED)



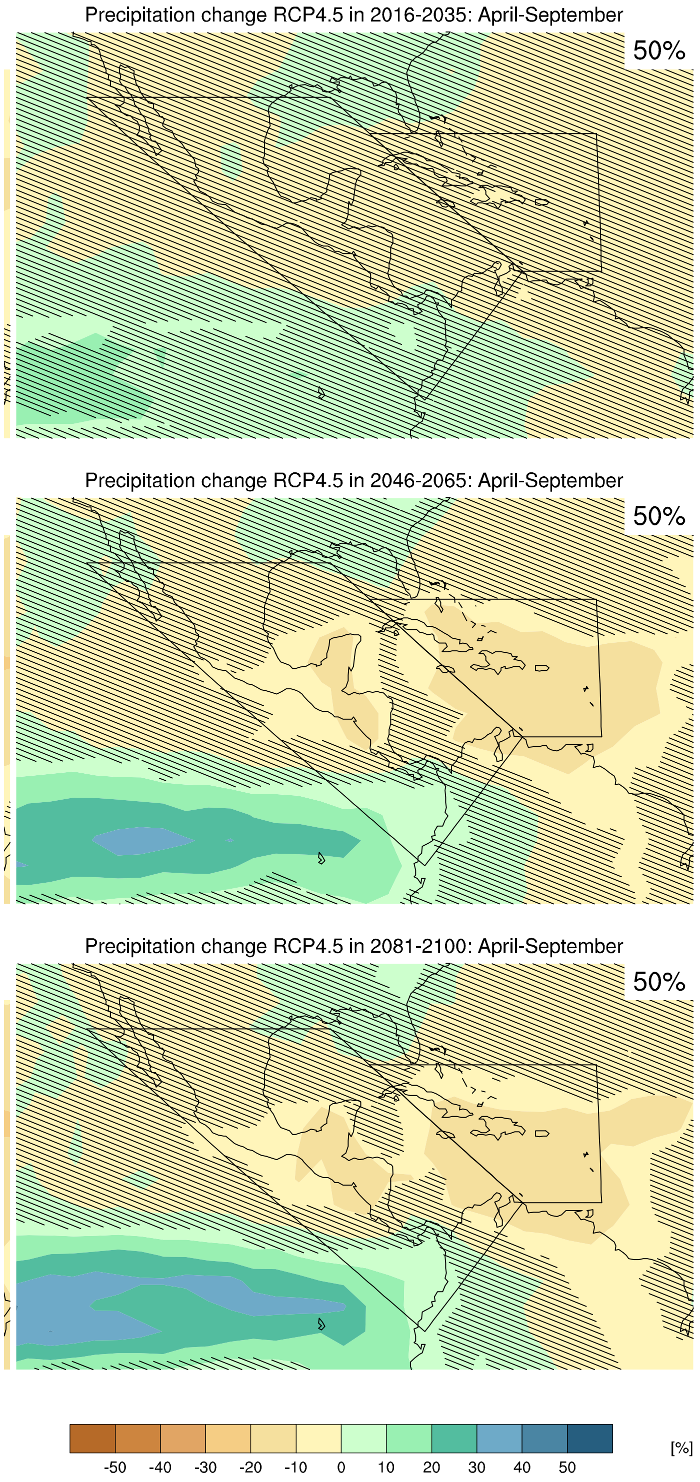
Note: Annual averages are shown by solid lines. Trends from linear regression are dashed lines.

Predicted changes in precipitation totals and seasonality

The recently released findings of the IPCC 5th Assessment sustain earlier IPCC projections showing long-term drying across Central America by mid to late century; this drying is maximized over Western Honduras and adjacent areas. As Figure 16 demonstrates, even under a moderate emissions scenario (RCP4.5) the net change in precipitation during the April-September period falls in the range of -10 percent to -20 percent by mid-century (2046-2065), which is more severe than reductions shown for eastern Nicaragua and southern Mexico to the East and West, respectively. Closer to the present, for the 20-year period centered on the year 2025, the predicted change (0 to -10 percent) over Western Honduras falls within the current range of variability (hatched areas in Figure 16); however, by 2046-2065, the dryness over western Honduras lies outside the current range of variability.

When taken with the model consensus of close to 2 °C of warming for the same time period relative to the present, these predictions suggest that by mid-century, Western Honduras may become a "hotspot" of magnified climate change related stress relative to areas outside the region. Furthermore, taking into account the recent trends of increased precipitation in Western Honduras, these predictions signify that a major reversal in precipitation would occur across the region during the next few decades.

FIGURE 16. MULTIMODEL CONSENSUS MAPPING OF PRECIPITATION CHANGES PREDICTED FOR 2016-2035 (TOP), 2046-2065 (MIDDLE), AND 2081-2100 (BOTTOM) WITH RESPECT TO 1986-2005 IN THE RCP4.5 SCENARIO



Note: At each time period, the 50th percentile of the distribution of the 42 individual model simulations used in the IPCC 5th Assessment are shown, including both natural variability and inter-model spread. Hatching denotes areas where the 20-yr mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-yr mean differences. Source: IPCC, 2014, excerpted from Figure A1.27.

The role of ENSO in temperature and precipitation trends

ENSO is a naturally occurring phenomenon in Western Honduras, which results from fluctuations of sea-surface temperatures and winds across the equatorial Pacific Ocean. El Niño affects the atmospheric circulations and precipitation globally, and its impacts are strongly felt over Central America and the Caribbean, including Western Honduras. Strong precipitation decreases relative to average typically occur during El Niño events in Western Honduras, which causes significant impacts on rain-fed agriculture and overall water availability for human consumption and ecosystems in the Dry Corridor region. During El Niño events in Western Honduras, basic grains planted during the *primera* season (May-August) are affected during the final crop development stages by a prolonged canícula, which can last an additional 20 or more days under El Niño conditions (FEWS NET, 2014). The *postrera* season (August-December) usually begins with below-average rainfall, delaying planting dates and disrupting seasonal sowing schedules (FEWS NET, 2014).

Climate model projections for Western Honduras for the remainder of the 21st century include considerable interannual variability due to patterns of ENSO phases, which may be of greater importance than global greenhouse gas buildup in driving temperature variability and trends for some years to come. The IPCC 5th Assessment report ascribes "high confidence" to the likelihood that ENSO will remain the dominant mode of interannual variability throughout the century, so comparable year-to-year temperature variability will continue, superimposed on an overall warming trend driven by greenhouse gas buildup in the global atmosphere (IPCC, 2013). Climatic variability can be expected to bring especially high levels of thermal and hydrological stress in El Niño years, with each decade bringing ever-higher degrees of such stresses.

Seasonal predictions of ENSO conditions before they develop will be particularly important for reducing vulnerability and increasing resilience to temperature-related risks in western Honduras, as elsewhere. Seasonal predictions of ENSO phase changes currently demonstrate considerable accuracy at the three-to-six month time range (International Research Institute for Climate and Society [IRI], 2013; for more information please visit www.iri.columbia.edu/climate/ENSO).

Tropical cyclones

Tropical cyclones (hurricanes, tropical storms, and tropical depressions) are low-frequency but high-impact events that affect Western Honduras on average once or twice per decade. Their primary impact on Western Honduras comes from high-magnitude rainfall events typically lasting one to three days, registered after the storm degenerates following landfall. Overall, the rugged topography of Western Honduras disrupts cyclone circulations and locally inhibits their formation. Despite such favorable factors promoting protection, past experience with decaying tropical cyclones, such as Hurricane Mitch in 1998 and Hurricane Fifi in 1974, demonstrate the high vulnerability of Western Honduras to severe flooding as a consequence of the passage of Caribbean storms.

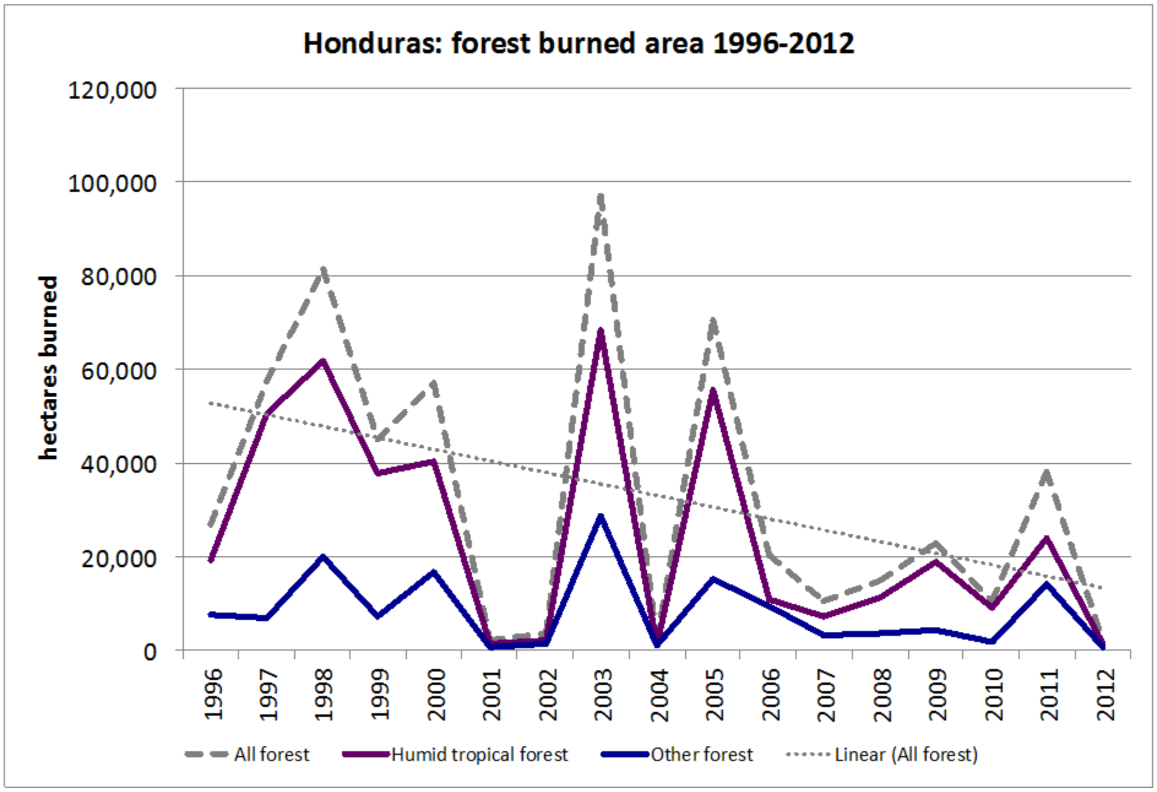
Risks of tropical cyclones may increase in Western Honduras due to warming seas and also the extension of the duration of the hurricane season. The warming of sea-surface temperatures off both the southern and northern coasts will foster conditions more supportive to tropical cyclone development than in the past. IPCC projections suggest that rainfall rates in the average storm will be ~15-percent higher by late century, which would mean that tropical cyclones affecting the region would register even higher impacts from flooding than at present (IPCC, 2013). However, a scientific consensus has yet to develop around the impacts of greenhouse gas warming on tropical cyclone occurrence.

Forest Fires

Fires of both natural and human origin across Western Honduras have been fundamental to regional ecology for millennia and will continue to be into the future. Whether caused deliberately for the clearing or regeneration of agricultural land or unintentionally, fire intensity and extent are strongly influenced by climatic conditions. Department-level data on forest fires from ICF from 2014 (through the end of April) indicate that more than 3,108 hectares had been affected by forest fires in the Western Honduras region during 2014. This figure represents approximately 8 percent of the total number of hectares nationally that had been affected by forest fires during 2014. The department of Intibucá had the highest number of hectares affected (1,393 hectares) while Copan had the highest number of forest fire incidents (50 incidents).

National-level statistics for Honduras obtained from the United Nations FAO allow a first-order view of the possible correlation between fire occurrences and climate. The FAO database contains the annual extent of burned areas in forested landscapes for the period 1996-2012 (Figure 17). The current wet period that began in 2007 is matched by corresponding low rates of burning and lower interannual variability than the decadal period that preceded it. How well this relationship applies in Western Honduras cannot be determined by the information provided; nevertheless, the reduction of the extent of burning between 2007 and 2012 is highly correlated with increased precipitation over this same period. As such, natural fire suppression due to increased rainfall may be part of the current reality throughout Western Honduras. However, a return to lower rainfall (as predicted by IPCC models) would likely reverse this trend.

FIGURE 17. TIME SERIES OF ANNUAL FOREST COVER BURNED OVER ALL OF HONDURAS COMPILED FROM SATELLITE DATA FOR THE PERIOD 1996-2012



Source: FAOSTAT

2.1.4 Key findings of the climate analysis

General climate characteristics of Western Honduras

- There is strong seasonality with an annual cycle featuring four distinct seasons.
- Western Honduras falls in the east-west oriented dry corridor of Honduras and adjacent Guatemala, with higher rainfall in areas to both the North and the South.
- Temperature is strongly related to elevation.
- Mountains, valleys, and land use are controlling factors in local climatological behavior, creating complex sub-regional variations in mean conditions.

Temperature trends and model predictions

- After a rapid multi-decade increase in temperature peaking in 1998, the temperature trend has been nearly neutral for the past 15 years, sustaining high baseline values above any experienced for many hundreds — likely thousands — of years.
- Natural variability governs annual-decadal temperature trends through the strong control exerted by the ENSO. The opposing phases of ENSO, El Niño and La Niña, typically cause monthly temperatures to be 0.75-1.0 °C above average and below average, respectively. In general, cooler temperatures are beneficial and are associated with lower rates of evaporation; hotter conditions intensify both thermal and hydrological stresses, especially to crops and other vegetation, and appear to exacerbate the effects of pathogens and pests.
- The period of hottest weather occurs in April and May, ending with the wet season onset.
- IPCC model predictions for the region show that temperature for the Central America region, including Western Honduras, is projected to increase by between 1.0 and 2.5 °C by mid-century under all four emissions levels assessed in the modeling studies.
- The IPCC ascribes high confidence to the likelihood that ENSO will remain the dominant mode of interannual variability throughout the century, so comparable year-to-year temperature variability should continue superimposed on an overall warming trend driven by greenhouse gas buildup in the global atmosphere.
- Absence of strong El Niño events since the late 1990s has suppressed occurrence of exceptionally warm years. There is, therefore, some potential for an upward jump in baseline temperature mean with the eventual (and possibly imminent) return to an El Niño-dominated pattern of Pacific Ocean sea surface temperatures.

Precipitation trends and model predictions

- Sub-regional differences are currently evident in duration and intensity of canícula period of reduced precipitation. The canícula is most strongly experienced along the east-west axis of the dry corridor, and much less so to the north and south.
- The past 16 years have seen widely varying rainfall trends across the project region. There has been an extremely large increase in the west, maximized around Ocotepeque (+35 mm/yr trend) and contrasted with the Santa Barbara region, where slight declines are observed.
- However, based on an analysis of frequency and intensity of rainfall in Ocotepeque and the northern Santa Barbara region, the number of days of rainfall has not increased, but precipitation events have

become more intense. This finding could partly explain perceptions from farmers that they are experiencing drier conditions overall, but that when it does rain, precipitation events have been more extreme.

For the most part, the current trends and model predictions are of opposite signs. The IPCC model consensus strongly asserts that significant drying of between 10 and 20 percent will characterize the regional climate by mid-century.

Tropical cyclones

- There have been low-frequency (one to two per decade) but high-magnitude events (up to 50 percent of annual rainfall/five days). The largest impacts to date have been registered by strong systems in the Caribbean coming ashore in Honduras and Nicaragua, bringing heavy rainfall to western Honduras.
- Risks may grow due to warming seas and also extension of hurricane season duration. Detailed climate model predictions of tropical cyclones are starting to become available but are inconclusive about how activity will evolve in the Central America region. The warming of sea surface temperatures off both the southern and northern coasts will foster conditions more supportive to tropical cyclone development than in the past.
- Rainfall delivery in tropical cyclones is expected to increase by approximately 15-20 percent by late-century as the climate warms, suggesting increasing risks of high-magnitude flood events.

Forest Fires

- Satellite-based assessments of forest burning since 1996 suggest that precipitation trends and variability exert considerable control over fire occurrence. This result, inferred from national-level analysis, would need to be refined to the regional level to be quantified for Western Honduras.

2.2 SENSITIVITY TO CLIMATE CHANGE

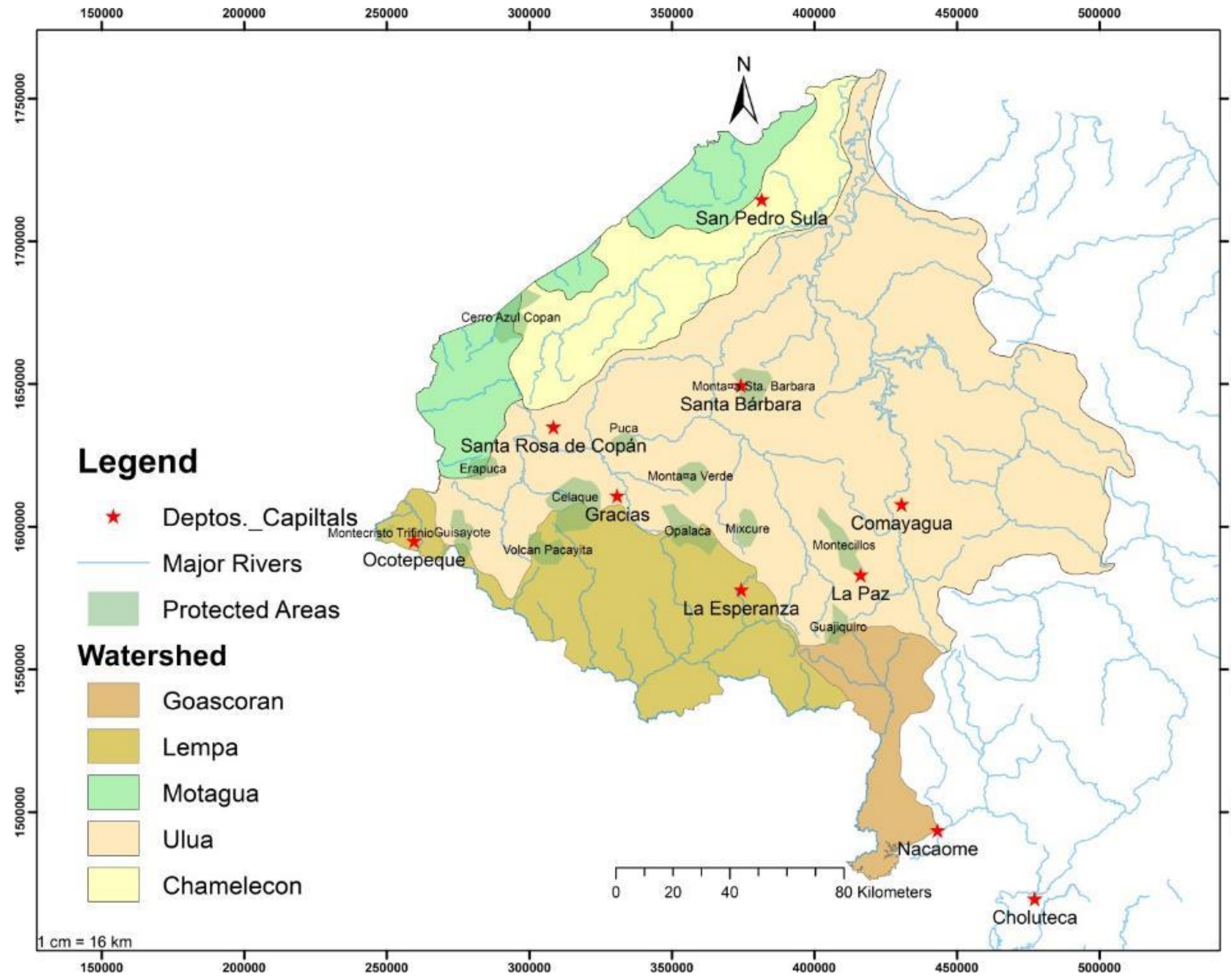
2.2.1 Sensitivity of ecosystems to climate change

This section analyzes the sensitivity of ecological systems in Western Honduras to climate variability and change through two interconnected analyses: an eco-hydrology analysis and Protected Areas analysis. The eco-hydrology analysis assesses land use/land cover and geomorphological and hydrological characteristics of key sub-watersheds in the region. An eco-hydrological vulnerability index is calculated for eight sub-watersheds in the region based on an analysis of key eco-hydrological variables (Permanent Land Cover Index and water production potential), which provide insights into the hydrological vulnerability of each sub-watershed. The Protected Areas analysis assesses the current functioning of Protected Areas in the Western Honduras region based on a review of secondary literature, KIIs, and FGDs. Together these analyses provide an in-depth understanding of the degree to which ecosystems in Western Honduras may be affected by climate-related stresses and shocks.

Eco-Hydrology Analysis

The hydrography of Western Honduras is composed of five major river basins: Lempa, Goascoran, Motagua, Chamelecon, and Ulua. Lempa and Goascoran rivers drain to the Pacific Ocean, while Motagua, Chamelecon and Ulua drain to the Atlantic Ocean (Figure 18). The region is the headwaters for the Lempa, Motagua, Chamelecon, and Ulua river basins. The Lempa and Motagua are transboundary river basins, shared by El Salvador and Guatemala, respectively.

FIGURE 18. MAJOR RIVERS AND WATERSHEDS IN WESTERN HONDURAS

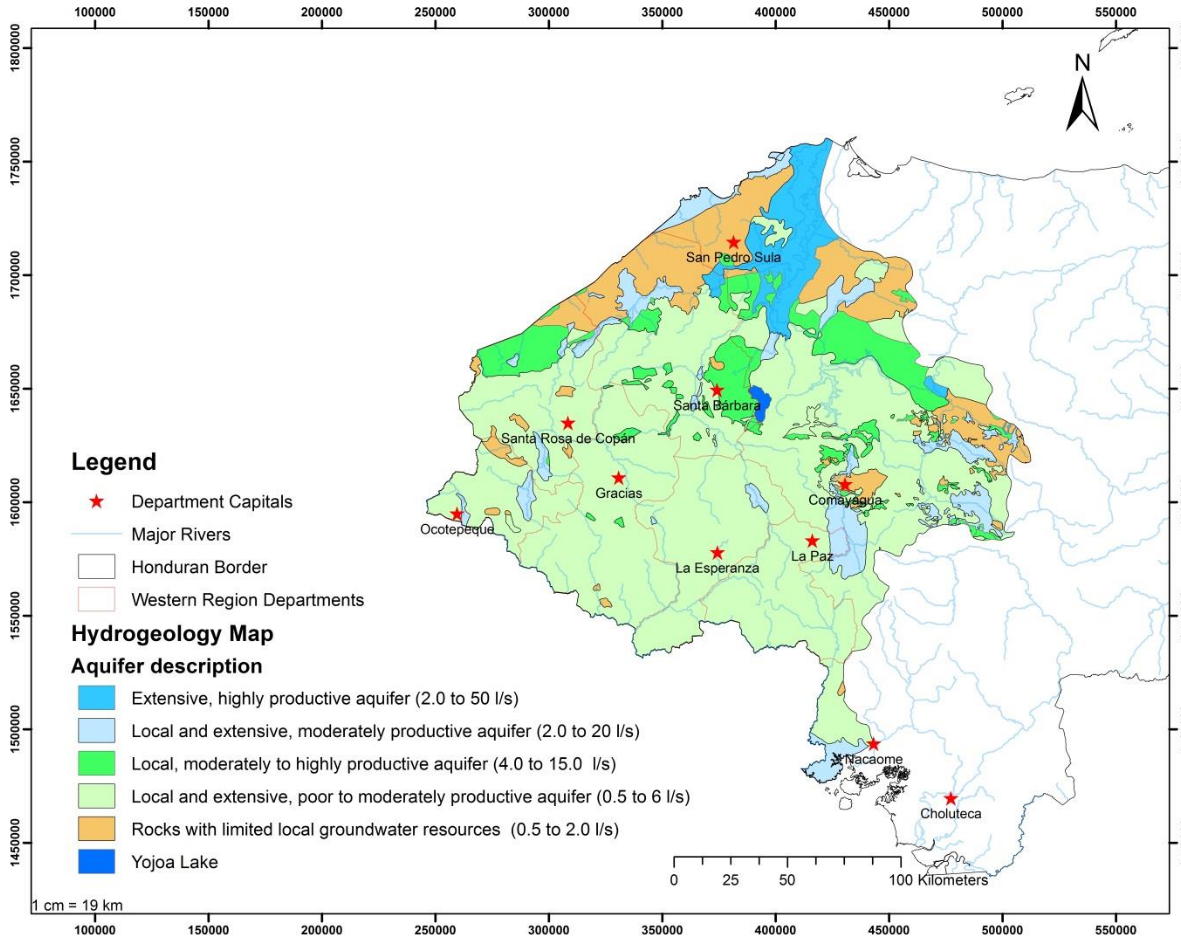


Surface water and groundwater resources of watersheds in Western Honduras

The Ulua watershed receives on average 1477 mm of precipitation annually and has an average real evapotranspiration loss of 1022 mm, resulting in 455 mm of water production potential per year. Rio Goascoran has an average of 1813 mm of precipitation per year, 1099 mm of real evapotranspiration, resulting in 713 mm of potential water production potential. Río Lempa receives an average of 1804 mm of precipitation annually while real evapotranspiration losses are 1126 mm, resulting in 678 mm of water production potential (Bailaron et al., 2010).

In the Ulua watershed, an average of 243 mm of water per year is used for groundwater recharge. In the Goascoran watershed, this value is 272 mm year and in the Lempa River Watershed 282 mm year. As the Western Honduras region is predominantly mountainous landscapes and the occurrence of aquifers depends largely on geological formation and topography, groundwater sources are considered limited, likely occurring along major rivers crossing intermountain valleys that have been formed by sediment deposits. According to the Honduran hydrogeology map (DIAT/SANAA, 2004), local and extensive aquifer formations are predominantly located along streams in Jesus de Otoro, Sensenti and Quimistan Valleys. As Figure 19 depicts, there is an extensive and high productive aquifer in the lower Ulua watershed; however, very limited groundwater resources exist in Rio Lempa and Goascoran upper catchments.

FIGURE 19. LOCATION AND PRODUCTIVITY OF AQUIFERS IN WESTERN HONDURAS



As discussed in the climate analysis in Section 2.1, climate models predict that significant drying will characterize the Western Honduras region by mid-century, accompanied by an overall warming trend driven by greenhouse gas buildup in the atmosphere. While the region will be characterized by a hotter and drier climate, rainfall intensity is expected to increase significantly during tropical storm events as the climate warms, which will increase the risks of high-magnitude flood events in the region. These changes in climate will have profound impacts on water resources in the Western Honduras region, which will interact with and exacerbate other anthropogenic pressures affecting water quantity and quality in the region, particularly where population growth rates and urbanization are high, such as in Santa Rosa de Copan, La Esperanza, Gracias, Ocotepeque, Marcala, and Santa Barbara. Land degradation from agricultural expansion and intensification, logging, and frequent forest fires due to drier conditions will place further stress on water resources. Socioeconomic factors such as economic growth and subsequent changes in food consumption patterns and overall livelihood conditions could pose additional stress on water resources. Below we discuss possible effects on water resources in Western Honduras, taking into account the climate projections identified in Section 2.1. These possible effects are based on a review of secondary literature on climate change impacts on water resources, supplemented by FGDs, KIIs, and field observations.

Possible effects on water resources in Western Honduras from a 10-20 percent reduction in precipitation and an increased likelihood of more intense precipitation events include:

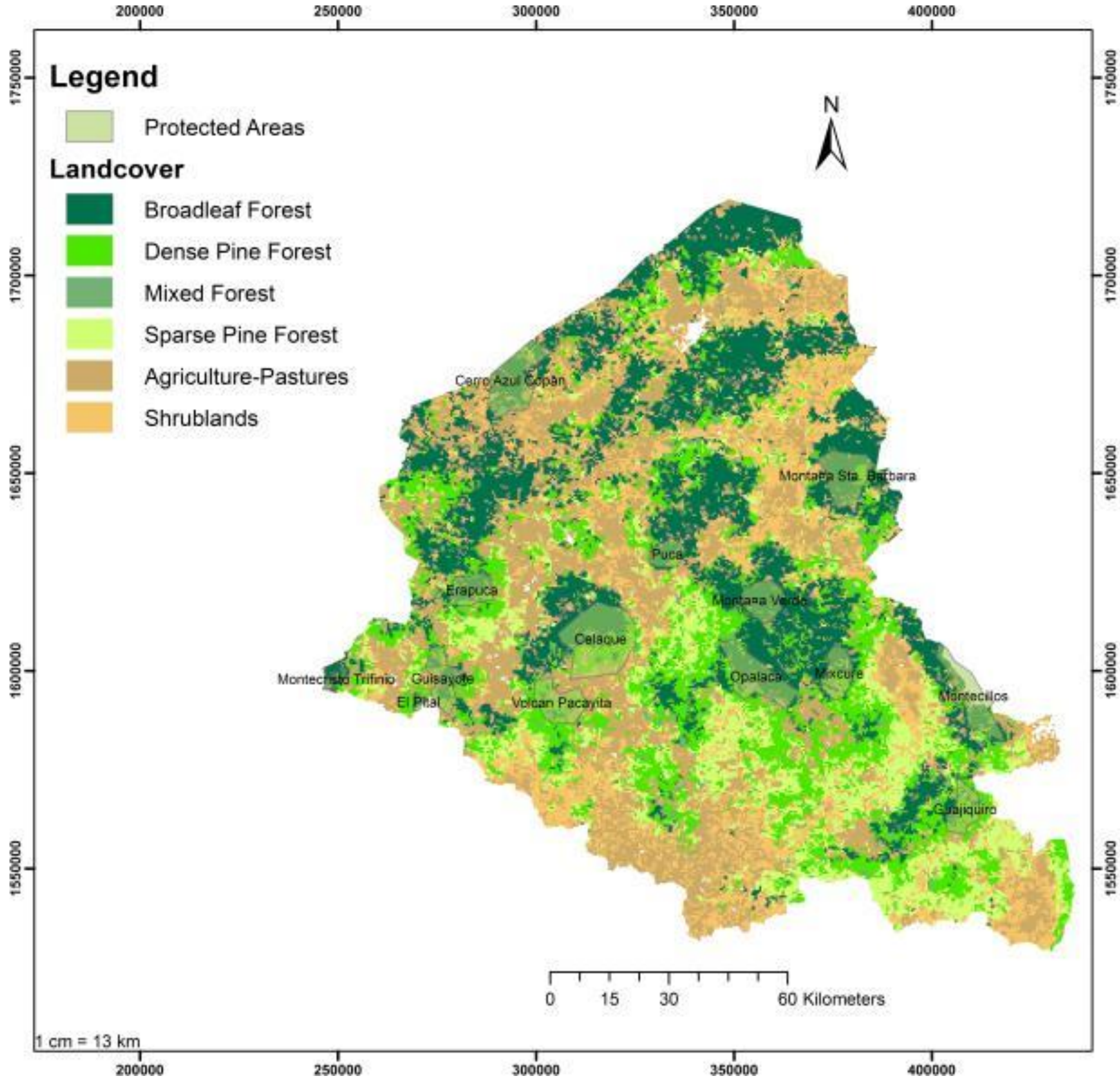
- Reduced total surface water availability for direct use by communities and urban areas, agriculture, and ecological processes;
- Decreased groundwater recharge rates, which could substantially affect dry season flows and therefore affect existing and future irrigated agriculture;
- Disappearance or reduced discharge rates of springs, which are an important water supply for rural communities;
- Reduced water inflows for reservoirs that provide current and future electricity generation (such as El Cajon and Nispero), thereby affecting the reliability of energy supply;
- Increased use of irrigation upstream, leading to increased water competition and potential water conflicts among competing users within the agricultural sector and/or between communities, as was noted as a current reality in Río Grande de Otoro sub-watershed during FGDs with farmers and local institutions; and
- Increased water pollution (sediments, nutrients, dissolved organic carbon, pathogens, pesticides, thermal pollution, and reduced oxygen content) due to longer periods of low flows and increased precipitation intensity with accompanying impacts on ecosystems, human health, water system reliability, and operating costs (IPCC, 2013).

Possible effects of an increase in temperature by between 1.0 and 2.5 °C include:

- Reduced soil moisture content due to higher evaporation levels;
- Increased irrigation water demand due to higher temperatures and evaporation rates;
- Increased susceptibility to forest fires; and
- Increased water pollution due to higher stream temperatures.

To determine the sensitivity of watersheds in Western Honduras to climate impacts, it is important to assess key indicators that make up a watershed's eco-hydrological vulnerability. Geomorphology (mean watershed slope, stream slope, etc.), land cover, and water production affect the quantity, quality, and timing of the flow of water from a watershed and provide an indicator of its overall eco-hydrological vulnerability and sensitivity to climate change impacts, including increased temperatures and precipitation variability and intensity. Figure 20 depicts land cover and land use in the Western Honduras region utilizing 2009 Moderate Resolution Imaging Sectroradiometer (MODIS) satellite observations, which are the most current land cover and land use data available. The map identifies seven classes of land cover and land use in Western Honduras: intensive agricultural areas (irrigated), rain-fed agricultural areas and pasture, urban areas, broadleaf forest, mixed forest, dense pine forest, sparse pine forest, water bodies, and shrublands.

FIGURE 20. LAND COVER AND LAND USE FOR WESTERN HONDURAS BASED ON MODIS DATA



Source: Rivera, et al., 2011

The type of vegetation in a watershed, i.e., the land cover, is the most important factor affecting watershed hydrology because of its effect on the rate at which precipitation either infiltrates into the ground or runs off the surface. A region's permanent land cover index (PLCI), which is the calculation of the percentage of permanent land cover in a region, measures the extent to which natural ecosystems have been conserved in a region. Permanent land cover is composed of vegetation that forms natural forest ecosystems, which is significantly more effective in allowing infiltration than other land uses, including croplands, pastures, shrublands, and urban areas. As conversion from forest to other land uses leads to a shift from primarily infiltration to primarily surface runoff (causing more rapid and higher peak flows following rainfall events) and to a reduction in dry season base flows (Grupta et al., 1974; Grupta et al., 1975; Bruijnzeel, 1989; Bruijnzeel, 2002), it can be used as an indicator of a region's sensitivity to climate-related impacts, particularly during extreme precipitation events and variability. In other words, a region with more permanent land cover is able to more effectively maintain its eco-hydrological functions and processes in the face of climate-related shocks and stresses, thereby making it is less sensitive to climate exposure than one in which natural vegetation has been cleared.

Watersheds with a low percentage of permanent land cover are subject to higher surface runoff, lower infiltration rates, more soil erosion, and lower base flows following precipitation events. Lower base flows persist into the dry season in these watersheds. Hanson et al. (2004) found that in the Talgua River watershed of Honduras, infiltration rates decreased by 100-fold when land cover changed from primary forest (infiltration rate: >840 mm/hr) to coffee plantation (89–109 mm/hr) to heavily-grazed pasture (8–11 mm/hr). Recent studies of two experimental watersheds with different permanent land cover ratios — in this case in areas with pine forests, shade-grown coffee, and crop agriculture — suggest that in areas with similar soils and climates, the permanent land cover ratio directly affects the ratio of infiltration to direct runoff. In the Zapotillo watershed, with a permanent land cover ratio of 59 percent, the runoff rate was 31 percent; meanwhile, the adjacent Capiro watershed, with a permanent land cover ratio of 39 percent, had a runoff rate of 39 percent (Bonilla Portillo and Garay, 2013). Thus, conversion from forest to other land uses leads to a shift from primarily infiltration to primarily surface runoff (causing more rapid and higher peak flows following rainfall events), and to a reduction in dry season base flows (Grupta et al., 1974; Grupta et al., 1975; Bruijnzeel, 1989; Bruijnzeel, 2002).

Based on an analysis of the 2009 MODIS land use and land cover data, the Western Honduras region has a PLCI of 60 percent, which can be considered a relatively high PLCI particularly when compared to other regions of Honduras[12]. As indicated in Table 2, pine tree forests (32 percent) and broadleaf forest (26 percent) dominate permanent land cover in the Western Honduras region, while agriculture and shrublands make up the remainder (40 percent). Broadleaf forest is a critical part of the ecosystem in Western Honduras. Much of the region's broadleaf forests are located at higher elevations (1,600 meters above sea level), which make up Western Honduras' cloud forests that are a critical source of the region's water resources. Western Honduras' 21 Protected Areas, which account for 13.3 percent of the region's total land area, contribute a significant portion of the region's permanent land cover.

TABLE 2. LAND COVER/LAND USE IN WESTERN HONDURAS

Land Cover/Land Use	Area (km^2)	Area (%)	Permanent Land Cover Index (%)
Irrigated Agricultural Areas	66	0.3	
Rain-fed Agricultural Areas and Pasture	5,061	23.1	
Urban Areas	6	0.0	
Broadleaf Forest	5,635	25.7	26
Mixed Forest	439	2.0	2

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[12] The PLCI for the Southern Honduras region is less than 50 percent (Byers et al., 2014).

Dense Pine Forest	4,070	18.5	19
Sparse Pine Forest	2,912	13.3	13
Water Bodies	86	0.4	
Shrublands	3,670	16.7	
Total	**21,944**	**100.0**	**60**

Table 3 provides an analysis of PLCI in Western Honduras by department. Despite Western Honduras' relatively high overall permanent land cover as compared to other regions, the PLCI varies considerably among departments within the region. For example, the departments of Intibucá and La Paz have slightly higher PLCIs of 67 percent and 66 percent, respectively, while Copan and Lempira have lower PLCIs of 51 percent and 53 percent, respectively. It is important to note that the high PLCI for the region is likely positively influenced by the effect of coffee production, as coffee is a permanent crop that is cultivated extensively throughout Western Honduras. However, it is not possible to accurately assess the magnitude of this effect, as coffee is not separated in existing land cover classification data.

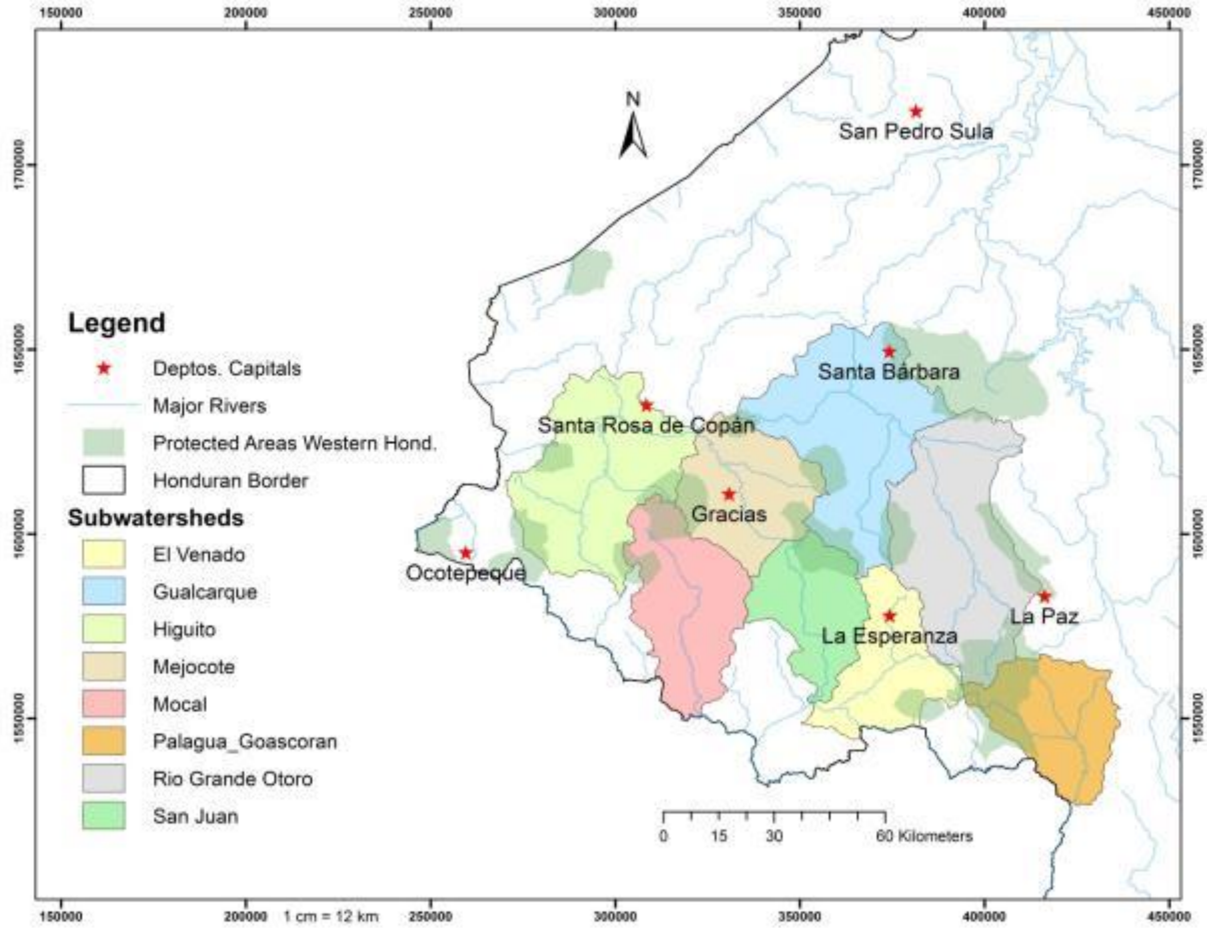
TABLE 3. PERMANENT LAND COVER DISTRIBUTION AMONG DEPARTMENTS IN WESTERN HONDURAS

#	Department	Area (km²)	Permanent Land Cover/Land use (km²)	Permanent Land Cover Index (%)
1	Intibucá	3,127	2,102	67
2	La Paz	2,535	1,668	66
3	Ocotepeque	1,636	948	58
4	Santa Bárbara	5,013	2,786	55
5	Lempira	4,286	2,251	53
6	Copan	3,240	1,659	51
	Total	**19,837**	**9,755**	**60**

Eco-Hydrology Analysis of Selected Sub-Watersheds

Due to the size of the watersheds in the Western Honduras region, which extend beyond the region itself, eight sub-watersheds were selected for further analysis as part of this eco-hydrology analysis: Río Mocal, San Juan, and El Venado (located within the Río Lempa watershed); and Higuito, Mejocote, Gualcarque, Grande de Otoro, and Goascoran-Palagua (located within the Ulua watershed). These sub-watersheds are part of the upper watershed recharge areas of Ríos Ulua, Lempa, and Goascoran. As previously discussed, the sub-watersheds were selected based on the following criteria: 1) they represent key recharge areas for Ríos Ulua, Lempa, and Goascoran and are therefore critical sources of water supply for the Western Honduras region; 2) they are located in the heart of the Dry Corridor, encompassing a representative range of livelihood zones and ecosystem types; 3) they provide key ecosystem services to important downstream population centers in the Western Honduras region; and 4) they have the potential to form an interconnected biodiversity corridor, both along watershed divides and along riparian areas that could enhance ecological resilience and biodiversity conservation in the region. Lessons from these sub-watersheds can be applied to other sub-watersheds in the Western Honduras region. Figure 21 depicts these sub-watersheds and demonstrates their spatial linkages with Protected Areas in the region.

FIGURE 21. SELECTED SUB-WATERSHEDS

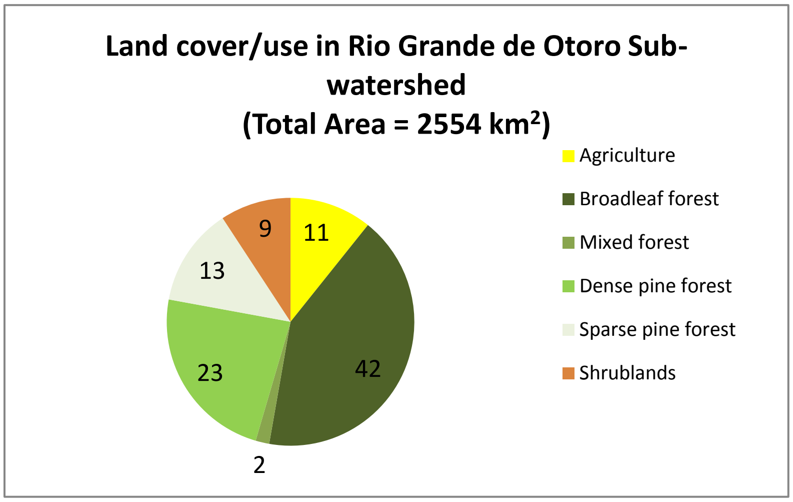


Description of sub-watersheds

In the following pages we provide a brief description of each sub-watershed to provide context for the eco-hydrological vulnerability analysis of sub-watersheds.

Grande de Otoro

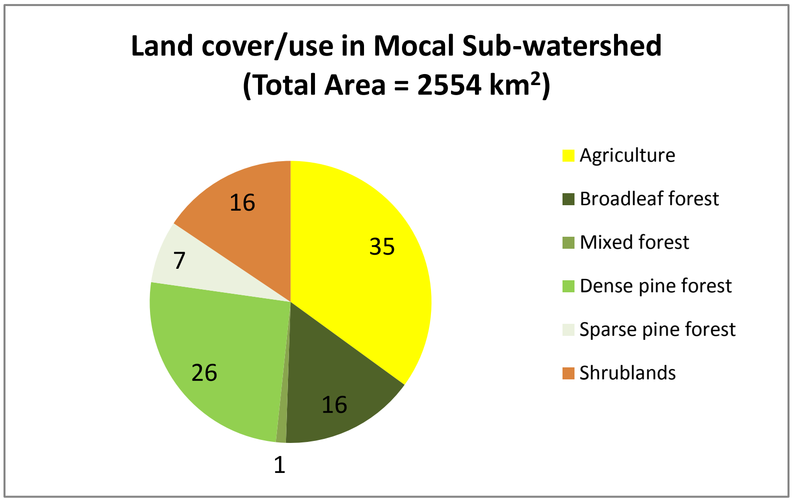
Grande de Otoro sub-watershed is an important headwater catchment tributary of the Río Ulua watershed. Major creeks within the sub-watershed include Santa Cruz and Grande de Otoro. These creeks drain from important Protected Areas within the region, including Mixcure, El Jilguero, Guajiquiro, Montecillos and Cerro Azul. Coffee farming is the most important economic activity in the sub-watershed, followed by basic grains, including maize, beans and rice. The sub-watershed is heavily forested (80 percent of the sub-watershed's land cover is forests), with the majority broadleaf forest (42 percent). This watershed contains a small valley (Jesus de Otoro Valley), in which farmers predominantly grow both irrigated and non-irrigated rice and practice extensive cattle farming. Approximately 190,000 people reside in the watershed resulting in a population density of 97 people per km². FGD participants identified the expansion of coffee production as causing deforestation, especially in the Biological Reserve Montecillo and upper recharge areas, creating increased sedimentation. FGD participants expressed concerns about the effects of perceived drier conditions on water availability for irrigated rice production.



Shade-grown coffee in Grande de Otoro Watershed. Photo by L. Caballero, 2014.

Mocal

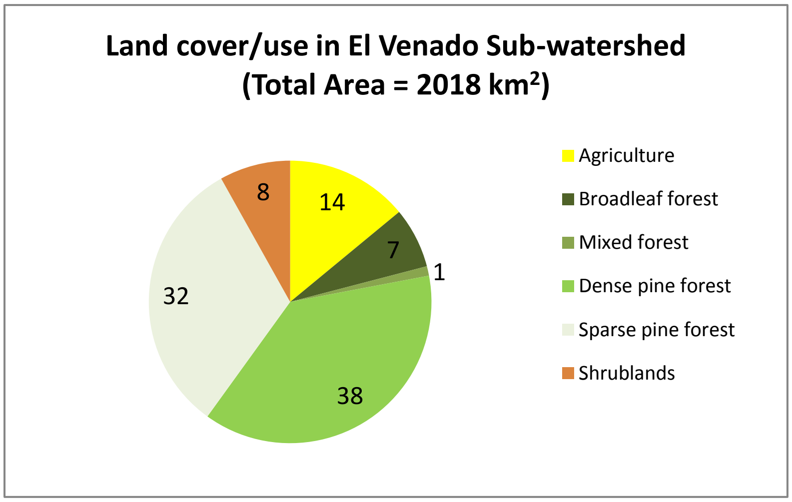
Mocal sub-watershed is one of the most important tributaries of the Lempa River. Its upper recharge area is partially located in the Celaque National Park. Land use is predominantly agriculture and fallow land and permanent land cover is 50 percent, composed mainly of dense pine forest (26 percemt), broadleaf (16 percent), and sparse pine forest (7 percent). The upper watershed has undergone high level of transformation from natural forest ecosystems to coffee plantation and maize and bean cultivation. This watershed has natural vulnerability associated with steep slopes (average 18 percent), which means that water is prone to leave the catchment in a short amount of time. Higher intensity storms could pose a significant risk for Mocal sub-watershed which could further increase the risk of soil erosion, landslides and impacts on crop productivity and food security.



Communal land for maize production in Mocal sub-watershed outside of Valladolid, Lempira. Photo by J. Parker, 2014.

El Venado

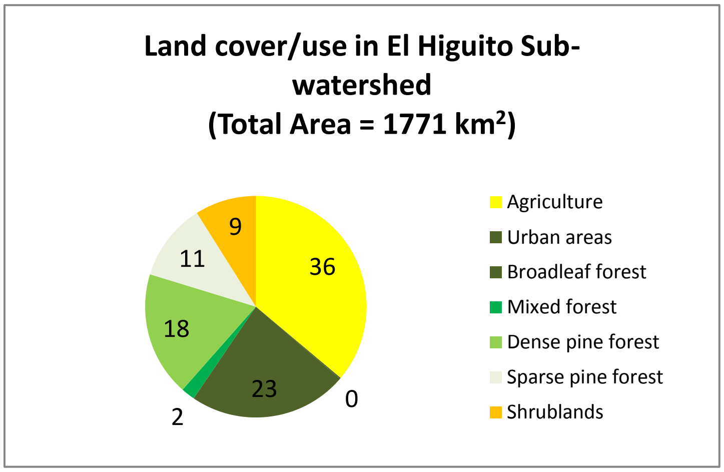
El Venado sub-watershed is an important tributary of the Río Lempa. It is located almost entirely within the area of the Dry Corridor that is considered "high drought risk". The land cover within Río Lempa is mainly composed of dense pine forest (38 percent) and sparse pine forest (32 percent) with a small amount of broadlead forest in the upper watershed area. Agriculture within the sub-watershed is predominantly maize and bean production, potatoes, and cattle farming. The sub-watershed has a high population density of 79 people per km^2. High levels of poverty characterize this sub-watershed, including at least ten of the poorest communities within Honduras (UNDP, 2013). Surface water sources are limited due to high infiltration, especially in the upper parts of the sub-watershed along watershed divides.



El Venado sub-watershed. Photo by L. Caballero, 2014.

El Higuito

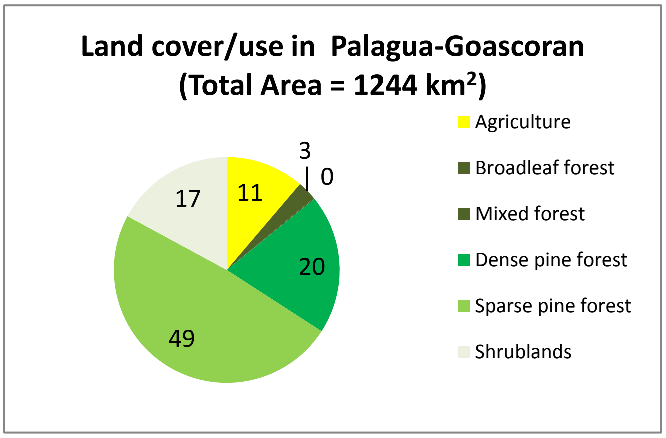
El Higuito sub-watershed is an important tributary of Ulua watershed. It has a total land area of 1,771 km^2 with land cover composed mainly of broad leaf forest (23 percent), dense pine forest (18 percent) and sparse pine forest (11 percent). There are an estimated 160,000 people within this sub-watershed with a population density of 90 people per km^2, which is the highest of the selected sub-watersheds. Major economic activities are associated with agricultural production, particularly coffee production and cattle farming, which drive commerce within the region. According to FGDs, horticulture is gaining importance in the sub-watershed, particularly potatoes, onions, and lettuce. Horticultural crops are produced primarily for local markets, with some sold in San Pedro Sula. Field observations identified that water supply is limited in this sub-watershed, especially along the Sensenti Valley, where most creeks appeared to be nearly dry during the dry season. Tributaries from four Protected Areas, Erapuca, Guisayote, Volcan Pacayita and Celaque National Park, drain into this sub-watershed. Permanent land cover is relatively low (54 percent), and signs of erosion are observable in agricultural lands and stream sediment transport is relatively high. Stream sedimentation could be increased due to the occurrence of more frequent highly localized and high intensity precipitation events.



Hillside maize production in El Higuito sub-watershed.
Photo by L. Caballero, 2014.

Palagua-Goascoran

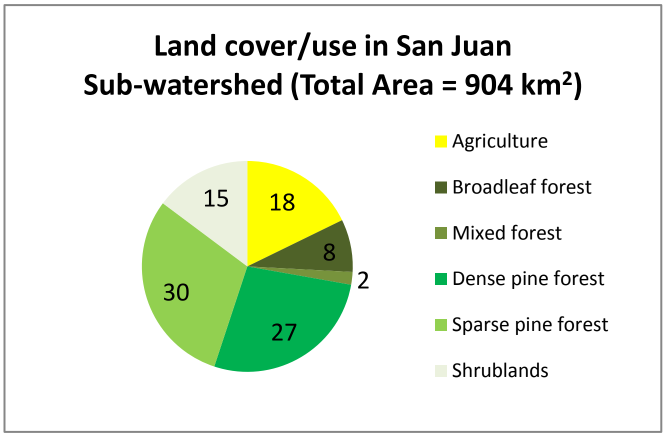
Palagua sub-watershed is the headwater of Río Goascoran. It drains from the Protected Areas of Jilguero and Guajiquiro. It has a total land area of 1,244 km^2 with land cover composed mainly of sparse pine forest (49 percent), dense pine forest (205) and of broad leaf forest (3 percent). Agricultural activities, mainly maize, sorghum and bean production, take place on hillsides but some commercial agriculture (cattle and basic grain production) is present in small valleys. In this sub-watershed there are an estimated 44,000 people with a population density of 43 people per km^2. There are no major population centers within the sub-watershed, therefore water resources, although limited, are not under pressure from human consumption. This sub-watershed is located entirely within the high drought risk zone of the dry corridor, therefore climate projections of increased temperatures and reduced precipitation will put further stress on the sub-watershed's limited water availability. Field observations identified that upper watershed areas have lost water retention capacity due to erosion and stream flow rises quickly during storm events.



Dry Season conditions in Palagua-Goascoran sub-watershed. Photo by L. Caballero, 2014.

San Juan

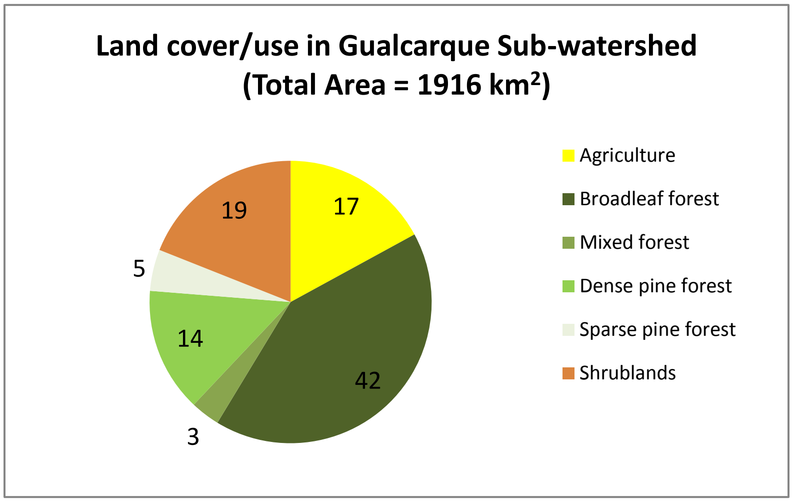
San Juan sub-watershed is an important headwater catchment tributary of Río Lempa. Its headwaters are located in the Opalaca Biological Reserve. Land use is predominantly composed of forest especially dense pine (30 percent), sparse pine (27 percent) and some broadleaf forest (8 percent). Agriculture and scrublands occupy 31 percent. Approximately 52,000 people reside in this sub-watershed, resulting in a population density of 58 people per km^2. Livelihoods are predominantly dependent on agriculture. Subsistence farming (maize and bean production) and remittances play an important role in the middle and lower watershed. Coffee is more common in the upper watershed along with some basic grains and cattle farming (FEWS NET, 2014). Field observations found that surface water resources are limited in the San Juan sub-watershed, making it vulnerable to increased water stress under climate projections of increased temperatures and reduced precipitation. According to the Honduran hydrogeology map, groundwater within the sub-watershed is considered local, extensive and poor to moderately productive.



San Juan sub-watershed.
Photo by L. Caballero, 2014.

Gualcarque

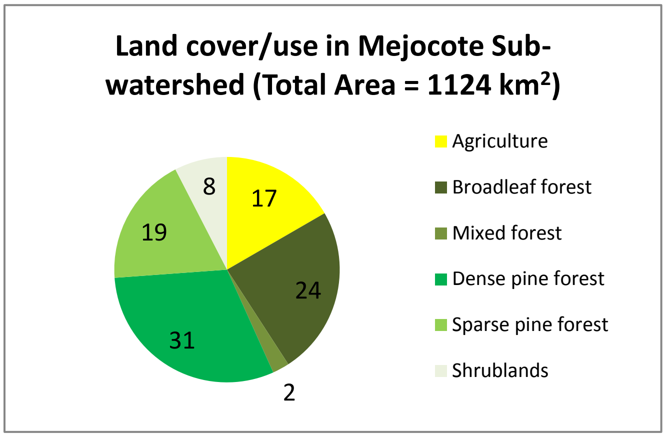
Gualcarque sub-watershed is an important headwater catchment tributary of Rio Ulua. Major creeks are Santa Cruz, Cumes and Grande de Otoro. These creeks drain from important Protected Areas Mixcure, Opalaca, Montaña Verde and Puca. This sub-watershed has a substantial amount of broad leaf forest (42 percent) and dense pine forest (14 percent). Coffee farming is the most important economic activity in the sub-watershed, followed by basic grains and extensive pastures for cattle. Approximately 190,000 people reside in the watershed resulting in a population density of 82 people per km2. This sub-watershed is an important water source for downstream users, including high population centers of Santa Barbara and San Pedro located in the middle and lower part of the basin, respectively.



Hillside production systems in Gualcarque sub-watershed.
Photo by L. Caballero, 2014.

Mejocote

Mejocote sub-watershed is an important headwater catchment of the Río Ulua Watershed. Major creeks are Guacamara and Mejocote. These creeks receive runoff and recharge water from the Protected Areas of Celaque, Opalaca, Montaña Verde and Puca. Land use is predominantly composed of broad leaf forest (24 percent), dense pine forest (31 percent) and sparse pine forest (19 percent). In this sub-watershed there are an estimated 77,000 people resulting in a population density of 68 people per km^2. The major population center is Gracias, which is one of the major water users from this watershed. Principal economic activities are associated coffee farming, followed by basic grains and extensive pastures for cattle. Irrigated horticulture is growing in importance, as it is being promoted as part of income generation and poverty reduction strategies of donors and the Honduran government. Field observation and interviews with small farmers indicate that water competition is increasing, and farmers are forced to move further upstream to tap new water sources. According to the hydrogeology map, there are limited groundwater resources in the Mejocote sub-watershed; water supply mainly comes from springs and surface water. A reduction of precipitation as predicted by climate projections will likely reduce recharge rates for these springs and creeks.



Mejocote sub-watershed. Photo by L. Caballero, 2014.

Table 4 provides an analysis of permanent land cover across all of the selected sub-watersheds. Permanent land cover across the eight sub-watersheds differs significantly. The highest values of PLCI are within Grande de Otoro and Mejocote sub-watersheds, with 80 percent and 78 percent, respectively. The lowest PLCI values are within Rio Lempa-Mocal and Higuito, with 45 percent and 55 percent, respectively (Table 4, following page).

TABLE 4. PERMANENT LAND COVER FOR SELECTED SUB-WATERSHEDS IN THE WESTERN REGION OF HONDURAS

Sub-Watershed Name	Total area (km²)	Permanent cover (km²)	Non-permanent cover (km²)	Permanent Land Cover Index (%)
Rio Grande de Otoro	3,445	2,756	689	80
Mejocote	1,124	852	272	78
Palagua-Goascoran	1,244	891	353	72
Lempa-San Juan	904	609	295	67
Lempa-Venado	979	632	347	65
Gualcarque	1,916	1,225	691	64
Higuito	1,771	966	805	55
Lempa Mocal	2,327	1,053	1,274	45

Table 5 assesses the basic geomorphological characteristics of the selected sub-watersheds. Geomorphological features determine how concentrated and rapid hydrological flows could be during and immediately after a rainfall event. Mean watershed slope provides an indication of how steep watersheds are, which influences how quickly runoff leaves a watershed. Stream slope indicates how steep streambeds are, which determines stream flow velocity and timing and how concentrated water will flow. As shown in Table 5, sub-watersheds in Western Honduras have high slope values, ranging from 14 to 18 percent, which indicates that these sub-watersheds are highly prone to a very rapid flow of both surface and sub-surface runoff. With such steep slopes, water can flow from the upper to the lower parts of the catchment very rapidly. Because of their steep slopes, climate projections of more intense precipitation events will further increase the risk of significant erosion and flooding in these sub-watersheds.

The shape of a watershed influences the way in which runoff concentrates at the mouth of the watershed. For example, runoff from rounder watersheds tends to concentrate and reach the mouth more quickly and with greater erosive power and velocity. The selected sub-watersheds demonstrate more elongate features (values between 1.29 and 1.69). In elongate watersheds, there tends to be less peak flow concentration than in rounder watersheds, unless there are other conditions contributing to flooding such as excess sedimentation of flood plains.

TABLE 5. SUB-WATERSHED BASIC GEOMORPHOLOGICAL CHARACTERISTICS, WESTERN HONDURAS

Sub-Watershed Name	Area (km²)	Perimeter (km)	Mean Watershed Slope (°)	Stream Slopes (%)	Watershed Shape
El Venado-Lempa	966	183.05	15	2.09	1.66
San Juan-Lempa	904	154.92	14	2.62	1.45
Mejocote	1,124	153.12	15	1.29	1.29
Higuito	1,771	232.82	14	0.93	1.56
Grande de Otoro	1,958	229.50	14	1.43	1.46
Gualcarque	1,916	261.87	15	1.69	1.69
Palagua-Goascorán	1,023	158.19	15	2.09	1.39
Mocal-Lempa	1,272	196.67	18	2.12	1.55

The most recent hydrological analysis (Balairon et al., 2010) for Honduras compares water production potential for the eight selected sub-watersheds. As depicted in Table 6, two contrasting results are presented for water production potential among sub-watersheds in the Western Honduras region: sub-watersheds draining to the Atlantic (Gualcarque, Rio Grande de Otoro, Mocal, and Higuito) have approximately 45 percent more water production potential than the Pacific-draining basins (Lempa Mocal, San Juan, El Venado, and Palagua-Goascoran).

TABLE 6. ESTIMATED WATER BALANCES FOR SELECTED SUB-WATERSHEDS IN WESTERN HONDURAS, BASED ON PUBLISHED DATA BY BAILARON, 2010, AND BAILEY ET AL., 2007.

Sub-Watershed Name	Precip-itation (mm/yr)	Total Expected Flow (mm/yr)	Total Water Potential (hm³/yr)	Average Flow (m³/s)	Water Production Potential Rate (Hm³/km²/yr)
El Venado-Lempa	1,542	122	120	4	0.12
San Juan-Lempa	1,545	139	126	4	0.14
Mejocote	1,646	238	268	8	0.24
Higuito	1,500	208	368	12	0.21
Grande de Otoro	2,078	438	1,509	48	0.44
Gualcarque	2,050	443	849	27	0.44
Palagua-Goascorán	1,612	152	367	6	0.15
Mocal-Lempa	1,878	317	736	23	0.32

2.2.2 Eco-hydrological vulnerability of selected sub-watersheds

Taking the results of the permanent land cover and hydrological analyses, we assessed the eco-hydrological vulnerability of sub-watersheds based on PLCI and water production potential in order to present an eco-hydrological vulnerability index for the selected sub-watersheds. As previously mentioned, eco-hydrological vulnerability can be defined as the extent to which ecosystem and hydrological functions of a watershed are likely to be damaged or disrupted by the impact of climate-related stresses and/or shocks. It was assumed that a sub-watershed with higher permanent land cover (and therefore a higher PLCI) and higher water production potential (and therefore less water stress) would be less eco-hydrologically vulnerable to climate exposure. Adapting the methodology used for the Southern Honduras Climate Change Vulnerability Assessment, we multiplied PLCI and water production potential to calculate the eco-hydrological vulnerability of each sub-watershed. Table 7 presents the eco-hydrological vulnerability of each sub-watershed based on these variables.

TABLE 7. ECO-HYDROLOGICAL VULNERABILITY INDEX OF SELECTED SUB-WATERSHEDS

Sub-Watershed Name	PLCI	Water Production Potential (Hm³/km²)	Eco-Hydrological Vulnerability Index	Eco-Hydrological Vulnerability Ranking
Palagua-Goascoran	0.72	0.15	0.108	3
San Juan-Lempa	0.67	0.14	0.094	2
Higuito	0.55	0.21	0.116	4
Gualcarque	0.64	0.44	0.282	7
Mocal-Lempa	0.45	0.32	0.144	5
Mejocote	0.78	0.24	0.187	6
Venado-Lempa	0.65	0.12	0.078	1
Grande de Otoro	0.80	0.44	0.352	8

The results of this analysis indicate that Venado-Lempa is the most eco-hydrologically sensitive to climate exposure, followed by San Juan-Lempa, Palagua-Goascoran, and Higuito. Venado-Lempa, San Juan-Lempa and Palagua-Goascoran have the lowest water production potential of the selected sub-watersheds. Consequently, under climate projections of increased temperature and reduced precipitation, these sub-watersheds would face even greater conditions of water stress, as climate impacts would further reduce already scarce water supplies for ecosystems, crops, and human consumption. The least eco-hydrologically vulnerable sub-watershed based on these results is Grande de Otoro, which has the highest PLCI and highest water production potential rate of the eight selected sub-watersheds. Grande de Otoro's high level of permanent land cover and high water production potential indicate that the sub-watershed has a greater ability to withstand the impacts of increased temperatures and reduced precipitation. However, as previously discussed, the predicted climate scenario of a 1.0-2.5 °C increase in temperature and 10-20 percent reduction in precipitation will result in significantly less water available within all sub-watersheds in the Western Honduras region, which will create more stressful conditions for ecosystems, crops, livestock, and communities. Section 2.2.10 expands on this analysis by combining the eco-hydrological vulnerability index with a social vulnerability index to determine the overall social-ecological vulnerability of these sub-watersheds.

While it is difficult to alter a watershed's geomorphology (stream density, watershed slope, shape, and soils), actions can be taken to "manage landscapes" within sub-watersheds in Western Honduras in a way that effectively builds their eco-hydrological resilience and enhances their ability to withstand climate change and variability. Actions to build eco-hydrological resilience within Western Honduras should focus on improving watershed management through increasing permanent land cover by protecting existing forest cover, enhancing soil and water management to increase water retention and groundwater recharge rates, and increasing crop water productivity through management practices that achieve more "crop per drop". A comprehensive strategy should focus on creating sustainable productive landscapes and applying land use planning at regional, watershed, and municipal levels. More specific recommendations and adaptation options by sub-watershed are detailed in Section 3.0.

2.2.3 Protected Areas analysis

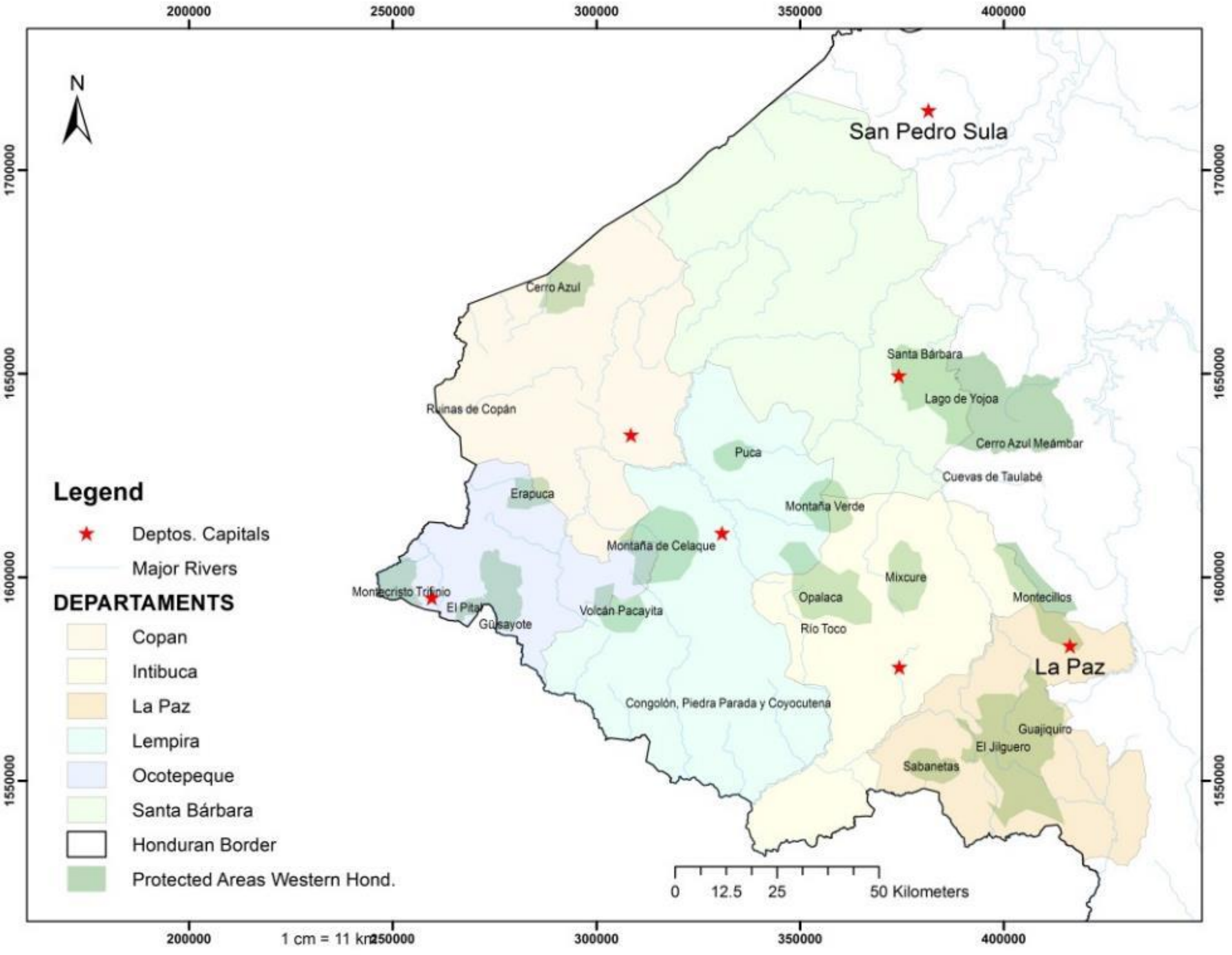
Protected Areas play a critical role in building resilience to climate change and variability by reducing vulnerability to floods, droughts, and other weather-induced problems; by protecting people from sudden climate events; and by supporting species to adapt to changing climate patterns by providing refuge and migration corridors (Monsourian et al., 2009). Figure 22 spatially depicts the Protected Areas in Western Honduras. There are 21 Protected Areas in the region, and they are classified into the following categories: National Parks (four), Biological Reserves (seven) Wildlife Refuges (four), Natural Monuments (three), Cultural Monuments (one); Multiple Use Areas (one); and Water Production Zones (one) (Annex 3). Protected Areas in Western Honduras make up approximately 13.3 percent (2,650 km^2) of the region's total area, providing critical habitats of biological significance and key ecosystem goods and services for livelihoods. As previously discussed, these Protected Areas make up a considerable portion of the region's permanent land cover. Annex 3 provides an analysis of each Protected Area in the Western Honduras region, including location, management category, description of the Protected Area, and principal institutions involved in Protected Area management.

Protected Areas in Western Honduras are critical for providing key ecosystem goods and services for communities in the region, including provisioning services (food, fiber, and freshwater); regulating services (climate factors, air, and water); support services (biodiversity, biomass, carbon sequestration, soil formation, and retention, etc.); and cultural services (scenic beauty) (Bezaury-Creel, 2009). Protected Areas in the region are particularly important for providing water supplies and for regulating local climate and hydrological flows; as such, the functioning of Protected Areas has a significant influence on the sensitivity of ecosystems to climate change and variability. For example, the Protected Area El Jilguero is designated as a "water production zone" that provides important water supplies to the Mancommunity of Lenca Municipalities of La Sierra de La Paz (MEMLESIP) and to 27 communities located within El Jilguero. Celaque National Park contains one of the most important cloud forests in Honduras and provides the water supply for more than 100 surrounding communities (Timms, 2007). The Biological Reserve of Guajiquiro is also critical for water production. An estimated 50 communities within in the Department of La Paz in the municipalities of Chinacla, Guajiquiro, Opatoro, San Pedro de Tutule, San José, Santa Ana, and Santa María depend on water supplied from this Protected Area. The Biological Reserve of Montecillos is also important for water production and regulates the climatic conditions on the Valley of Jesus de Otoro. The Biological Reserve Opalaca provides the water supply for 45 communities located inside the reserve and many other communities located in the buffer zone. Biological Reserve Opalaca is an important recharge area for 13 microwatersheds that drain into Ríos Lempa and Ulua: Río Jagua, Río del Naranjo, Río Conchagual, Río Negro, Río Zarco, Río Pacayal, Río Grande de Manazapa, and Río Monquecagua (that drain to Río Ulua); and the microwatersheds of Río Gualamota, Río Toco, Río San Juan, Río Mangual, and Río Azacualpa (that drain to Río Lempa).

KIIs and FGDs highlighted significant threats that are degrading the Protected Areas in the region, which are undermining their ability to provide these key ecosystem services and reduce vulnerability to climate change. The most significant threat facing Protected Areas in Western Honduras is agricultural expansion, mainly driven by the expansion of coffee production and subsistence crops (maize and beans), with underlying drivers of rural poverty and policy and governance failures. For example, in the Biological Reserve Sabanetas, coffee production has expanded into the core zone of the Protected Area, as producers are seeking improved microclimates for production (House and Rivas, 2008). Participants in FGDs indicated that increasing temperatures are a key factor behind the expansion of coffee production to higher altitude zones and into Protected Areas. In Biological Reserve Montecillos, habitat fragmentation due to agricultural expansion has resulted in significant disruption of habitats for native flora and fauna populations. In the opinion of some interviewed stakeholders, the Biological Reserve Montecillos "is undergoing accelerated degradation due to a lack of interest by local and national authorities and by civil society and the general public."

Of the 21 Protected Areas in Western Honduras, only seven have management plans (Opalaca, Celaque, Puca, Guisayote, Montecristo, Trifinio, Cerro Azul Copan, and Santa Barbara). An analysis of these management plans revealed that there are no specific programs, strategies, actions, or activities related to adaptation to climate change. The National Institute of Forest Conservation (ICF) has made significant progress in the development of methodological tools for managing Protected Areas; however, they do not have the required institutional presence in the field, much less the committed financial resources to fulfill their constitutional commitment to manage or co-manage the Protected Areas in Western Honduras.

FIGURE 22. LOCATION OF THE 21 PROTECTED AREAS IN WESTERN HONDURAS

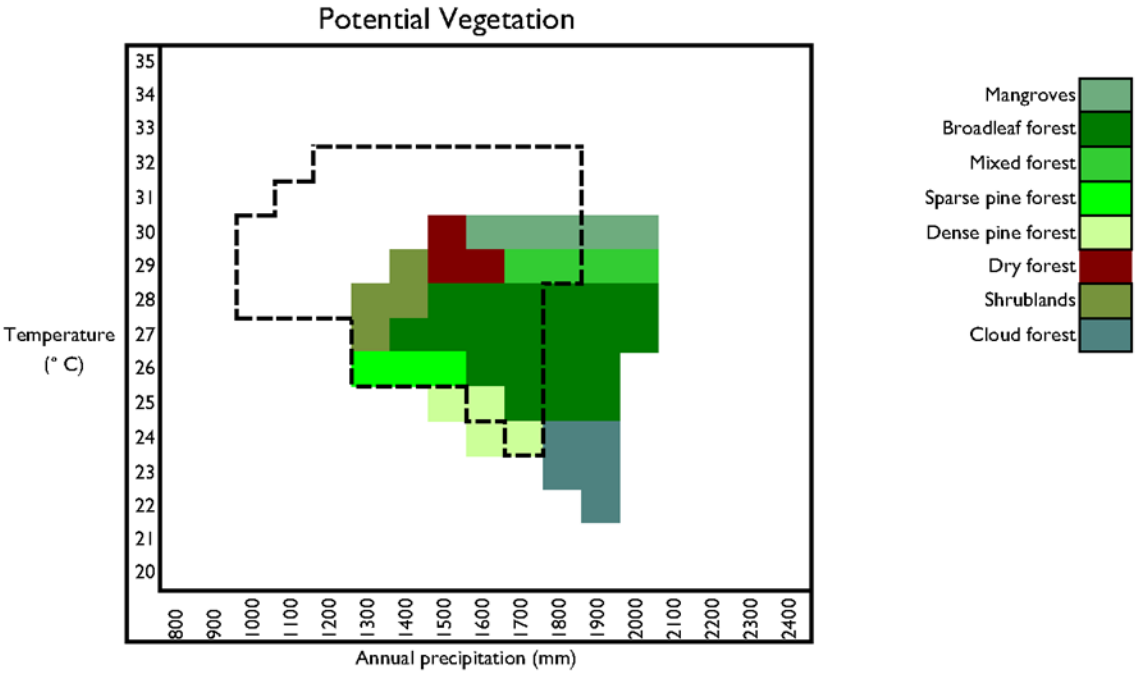


The predictions from the IPCC Fifth Assessment Report under a high-emissions scenario (temperature increase of +2 °C and a precipitation decrease of between 15 and 20 percent) will have significant impacts on natural ecosystems and Protected Areas in Western Honduras. Figure 22 displays a climate envelope diagram that was developed for the Southern Honduras Vulnerability Assessment to show how natural ecosystems in Honduras are distributed with respect to current temperature and precipitation levels. Ecologists often use temperature and precipitation to characterize “climate envelopes” for species and ecosystems (Whittaker, 1975). These “envelopes” outline the combinations of temperature and precipitation within which a species or ecosystem is found. The climate envelope diagram in Figure 23 shows how natural ecosystems of Southern and Western Honduras are distributed with respect to current temperature and precipitation levels. The dotted outline in the diagram shows how the ecological climate envelope would shift by 2050 if the predictions from the IPCC Fifth Assessment Report for a high-emissions scenario were to occur (a temperature increase of +2 °C and a precipitation decrease of –15 percent, about 200 mm less than at present).

The climate conditions outside of the dotted outline on the right side of the diagram — that is, those areas with precipitation above 1,800 mm/year in the current climate — would probably disappear from the region. Under this scenario, areas in Western Honduras suitable for cooler, moister forest types — broadleaf forests, mixed forests, and pine forests — would decrease, and areas suitable for cloud forests would completely disappear. This situation would have profound impacts on Protected Areas in Western Honduras. At least 15 Protected Areas in the region contain cloud forests, including Celaque, Opalaca, Montaña Verde, Puca, El Jilguero, Guajiquiro, Sabanetas, Montecillos, Mixcure, Volcán Pacayitas, El Pital, Montecristo Trifinio, Cerro Azul Copán, and Montaña de Santa Barbara. Climate impacts on cloud forests would, in turn, directly affect water supply for the thousands of communities in the Western Honduras region that depend on these Protected Areas and ecosystems for water resources. While areas suitable for cooler, moister conditions would significantly decrease, areas with climates suitable for shrublands and dry forests would increase.

The white area inside the dotted outline (above and to the left of the current climate envelope) show new temperature-precipitation combinations that currently are not found in the region but would be added, i.e., the white area will be drier and warmer than any climates now found in Western Honduras. Out of a total of 40 grid cells that correspond to natural ecosystems in Western Honduras, 20 cells of currently existing area would be lost from the cooler and wetter side of the diagram, and an equal number would be gained on the hotter and drier side. This change amounts to 50 percent of the current temperature-precipitation climate envelope in Western Honduras. The predicted changes would affect ecological functioning and therefore the products and services that these ecosystems provide (Grimm et al., 2013; Nelson et al., 2013).

FIGURE 23. CURRENT CLIMATE ENVELOPE FOR ECOSYSTEMS IN SOUTHERN AND WESTERN HONDURAS AND SHIFT BASED ON IPCC 2050 CLIMATE SCENARIO



Source: Assessment Team (ARCC, 2013b). Annual precipitation values in this matrix are based on satellite-observed rainfall (TRMM) validated by point-source measurements from regional climate stations. Temperatures are inferred from the standard reduction in temperature as a function of height in the tropics (a reduction of ~0.5 °C per 100 m increase in elevation) with long-term means at regional weather stations operated by the Servicio Meteorologico Nacional *providing reference baselines. Land use data is drawn from Rivera et al., 2011.*

2.2.4 Key findings of the ecosystems analysis

- Predicted changes in climate for Western Honduras will have profound impacts on water resources in the region, which will interact with and exacerbate other anthropogenic pressures affecting water quantity and quality, particularly where population growth rates and urbanization are high, such as in Santa Rosa de Copan, La Esperanza, Gracias, Ocotopeque, Marcala, and Santa Barbara. Likely climate change impacts on water resources include declining surface water availability and decreased groundwater recharge, lower river flows and water levels, reduced soil moisture, increased irrigation water demand, intensified flood events, and increased water pollution.

- PLCI, which measures the extent to which natural ecosystems have been conserved in an area, differs significantly across the selected sub-watersheds. The highest values of PLCI are within Grande de Otoro and Mejocote sub-watersheds, with 80 percent and 78 percent, respectively. The lowest PLCI values are within Rio Lempa-Mocal and Higuito, with 45 percent and 55 percent, respectively.

- An analysis of water production potential, which helps identify the level of water stress within sub-watersheds, presents two contrasting results: sub-watersheds draining to the Atlantic (Gualcarque, Rio Grande de Otoro, Mocal, and Higuito) have approximately 45 percent more water production potential than the Pacific-draining basins (Lempa Mocal, San Juan, El Venado, and Palagua-Goascoran).

- An eco-hydrological vulnerability analysis, which integrates the results of the sub-watershed analysis of PLCI and water production potential, identifies Venado-Lempa as the sub-watershed that is most eco-hydrologically sensitive to climate exposure, followed by San Juan-Lempa, Palagua-Goascoran, and Higuito. This means that under climate projections of increased temperature and reduced precipitation, these sub-watersheds would face even greater conditions of water stress, as climate impacts would further reduce already scarce water supplies for ecosystems, crops, and human consumption. Based on these results, the least eco-hydrologically vulnerable sub-watershed is Grande de Otoro. Grande de Otoro's high level of permanent land cover and high water production potential indicate that the sub-watershed has a greater ability to withstand the impacts of increased temperatures and reduced precipitation.
- The 21 Protected Areas of Western Honduras conserve more than 13 percent of natural vegetation in the region (i.e., permanent land cover) and therefore significantly contribute to the region's PLCI. They play a critical role in building resilience to climate change and variability in the region by reducing vulnerability to floods, droughts, and other weather-induced problems; protecting people from sudden climate events; and supporting species to adapt to changing climate patterns by providing refuge and migration corridors.
- KIIs and FGDs highlighted significant threats that are degrading the Protected Areas in the region, notably agricultural expansion for both subsistence crops (maize and beans) and coffee production. Increasing temperatures were identified as a key driver of the expansion of coffee production to higher altitude zones and into Protected Areas.
- Climate change predictions for the region will have significant impacts on natural ecosystems and Protected Areas in Western Honduras. Areas suitable for cooler, moister forest types — broadleaf forests, mixed forests, and pine forests — would decrease; areas suitable for cloud forests would completely disappear. This situation would have profound impacts on Protected Areas in Western Honduras as at least 15 Protected Areas in the region contain cloud forests that supply water for thousands of communities in the region. Areas with climates suitable for shrublands and dry forests would likely increase.

2.2.5 Sensitivity of crops to climate change

This section examines the sensitivity of key crops and value chains in Western Honduras (coffee, maize, beans, and two horticultural crops, lettuce and potatoes) through a phenological analysis. These crops were selected because they represent the main crops cultivated by farmers in Western Honduras as identified by secondary literature and FGDs; they are also critically important for food and livelihood security in the region. Additional information on the importance of these crops for the Western Honduras region is provided in the phenological analysis, value chains analysis, and livelihoods analysis sections. The phenological analysis assesses the potential impact of projected climate change — specifically changes in temperature and precipitation — on the overall productivity of the targeted crops. To determine the sensitivity of coffee, maize, beans, lettuce, and potatoes to climate change and variability, the phenological analysis took into account: 1) ranges of temperature and precipitation required for the development of each crop, specific to Western Honduras; 2) climate projections for Western Honduras based on the findings of the climate analysis; and 3) the potential impact on plant development under these projected climatic conditions at different phenological stages. The analysis involved a detailed review of peer-reviewed literature and technical reports, supplemented by information gathered from KIIs and FGDs with farmers and institutions.

Phenological Analysis of major crops in the Western Honduras region

Agriculture is an inherently risky endeavor with a wide range of biotic and abiotic (including climate) factors that interact in a dynamic fashion at various stages of the growth cycle to determine the productivity of a given crop or season. Not only do alterations in climate or weather influence the productivity of crops, they also indirectly affect biotic factors such as diseases, pests, vectors, and weeds, thereby creating conditions that either favor or impede growth and thus affect the crop in question.

Known climate-related variables that alter crop phenology[13] and productivity include CO_2, radiation, temperature, crop characteristics, water, weeds, pests, diseases, pollutants, and nutrients. These variables, which are often affected by climate-related factors, play an important role in crop life cycles and overall productivity. This phenological analysis draws upon existing literature, data, and research to (1) develop a better understanding of the major phenological characteristics (phenophases) of selected crops; (2) develop insights into how these crops are likely to respond to climate change – specifically changes in temperature and precipitation; and (3) assess the potential impact of projected climate change on the overall productivity of the selected crops. The phenological analysis focuses on the targeted crops for this assessment: maize, beans, coffee, and two horticultural crops, lettuce and potatoes.

Like all living things, crops enjoy a range of optimal conditions for growth and development at different phases of the life cycle. While crops can continue to grow and produce under a wider range of less optimal conditions, their productivity is affected, and some crops are more resilient to changing climate conditions than others. In addition, the impact of changing temperatures or precipitation on crop productivity is complex and can interact in unexpected and contradictory ways. For example, certain conditions might favor the productivity of a given crop but also favor the growth and proliferation of a particular disease or pest, which, if not controlled, will lead to damaged crops and lower yields and quality. Below, for each targeted crop, we summarize the impact of changes in temperature and precipitation on crop development at various stages of the growth cycle, as well as on a selection of particularly troublesome pests and diseases that pose the greatest risks to each of the crops under review. Annex 4: Phenological Analysis summarizes these impacts in more detail.

Coffee

Coffee represents the most important cash crop in Honduras (Guerrero, 2014). All of the visited regions cultivate coffee, even in lower elevation regions that are prone to rust infection and are less productive. Use of nurseries ("*viveros*") to germinate seeds and produce seedlings for transplant has a positive impact on protecting coffee plants against climate extremes, as it reduces vulnerability of the crop at the vegetative stages of seed germination, emergence, and early plant elongation. Climate and pest/disease impacts on coffee largely depend on the quality of cultural practices at planting. Transplanting young plants is a particularly vulnerable stage if climate conditions are challenging and pest/disease pressure is significant, as coffee plants are still fragile from a physiological/developmental standpoint and require a period of adaptation to new conditions. Floral initiation, anthesis, and flowering are critical stages in plant development. It is reported that flowering requires environmental signaling in the form of 7-10 mm of water shortly after a brief drought period. Alterations of this balance have

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[13] Phenology is the study of recurring biological phenomena and their relationship to weather, such as seasonal and interannual variations in climate. It is generally related to the effect of climate on the timing of biological events, such as the first emergence of buds and leaves, or date of harvest (Hermes, 2004).

negative impacts on both flowering and fruit development, affecting yield and bean quality. Excessive rain and prolonged drought are significant constraints for proper fruit development (Eakin et al., 2005).

Coffee Leaf Rust, which is the most serious disease affecting the Western Honduras region, is most prevalent at elevations below 1700 meters (Avelino et al., 2004; Avelino et al., 2006). Information gathered through FGDs identified that farmers in the Western Honduras region are now moving into higher elevations to counteract problems with the fungus. Additional research is needed to develop improved varieties that are more resistant to rust and climate change impacts of increased temperatures and precipitation variability (Eakin et al., 2006). Among the most promising of improved varieties for Western Honduras is the Catimores, which is more resistant to rust and performs well at lower elevations and warmer temperature conditions (Van der Vossen, 2009). FGDs identified that Catimores varieties such as Lempira and IHCAFE-90 are currently used throughout Western Honduras and have replaced traditional varieties such as Bourbon, Indio, and Caturra. Arabica varieties, such as Pacas and Catuai, are still used in La Esperanza and Tomala despite their lower levels of rust resistance; however, farmers indicated that the high quality of these varieties make them worth the risk.

Climate change impacts on coffee productivity

There is a very high potential for decreased productivity of coffee due to climate change impacts, particularly during flowering and fruit development. Changes in the timing of rain and dry periods during floral development have significant impact on fruit and grain development. This scenario is possible as climate projections in Western Honduras indicate more irregular precipitation patterns. Coffee varieties respond sensitively to increasing temperatures, specifically during blossoming and fruit development. Controlled conditions at planting and early vegetative stages make coffee plants significantly less vulnerable to changes in climate conditions. However, unfavorable climatic events in early transplanting, drought in particular, would affect the plants significantly. There is a very high potential for increased prevalence of Coffee Leaf Rust, particularly under increased rainfall and warmer-than-normal temperature scenarios.

Climate change impacts on pests and diseases

- **Roya (Coffee Leaf Rust) *Hemileia vastatrix***. There is very high potential for an increase in the prevalence of Coffee Leaf Rust due to climate change, particularly under increased rainfall and warmer-than-normal temperature scenarios. In addition, coffee rust may have developed new strains with enhanced adaptability and stronger resistance to agrochemicals. Studies by Avelino et al. (2004 and 2006) indicate that warming temperatures at higher elevations and subsequent shifts in moisture levels have enabled Coffee Leaf Rust to migrate to regions where it was previously not a serious problem.

- **Broca del Café (Coffee Berry Borer) *Hypothenemus hampei***. There is moderate potential for an increase in the prevalence of Coffee Berry Borer, particularly under decreased rainfall and warmer-than-normal temperature scenarios. An increase of rains early in the season can enhance borer infestation.

- **Ojo de Gallo (Coffee Leaf Spot) *Mycena citricolor***. There is high potential for increased prevalence of *Ojo de Gallo*, particularly under increased rainfall and warmer-than-normal temperature scenarios. *Ojo de Gallo* is more prevalent in areas of excessive shading.

- **Mal de Talluelo ("Damping Off" disease) *Rhizoctonia solani***. There is moderate potential for increased prevalence of Rhizoctonia, particularly under increased rainfall and warmer-than-normal temperature scenarios. Rhizoctonia infects below-ground parts of plants and it is particularly favored in extended periods of wet weather. Coffee plants can be very susceptible at early vegetative stages.

Coffee Production in the Higuito sub-watershed. Photo by L. Caballero, 2014.

Potato

Potato is a crop adapted to cool and moderate temperatures. In general, potato grows at high elevations (above 1400 m) and in places with temperatures in the range of 12-24 °C. Potato plants are quite vulnerable to both excess water and drought, in particular during planting and at early vegetative stages. In addition, plants are susceptible to low temperatures (i.e., unexpected frost in the middle of the growing season). Potato plants need around 500 to 1200 mm of annual rainfall to complete growth. Poor plant growth will affect tuber development and, consequently, affect yield and quality of the crop. It was evident that the quality of potatoes in Western Honduras are hampered by the use of poor seed quality. All of the potato varieties in Honduras are foreign varieties with varying levels of adaptation to local conditions. The most common potato variety in Ocotopeque and Intibuca is the variety Bellini, followed by Provento, both of which are Dutch varieties. In the past other varieties were used, including Toyoca, Alpha, Atzimba, and Papa Colorada, but their cultivation was abandoned due to changes in consumer preferences, poor production, and/or increasing pest/disease susceptibility. Virus contamination is one of the most serious limitations of tuber seeds and it limits plant growth due to poor health. Potato plants are more resilient in later stages of plant development, in particular during the reproductive stages.

In recent years, one important pest in potatoes is the *paratrioza* (Potato Psyllid, B. cockerelli). It is possible that contaminated potato seeds that entered the country were responsible for bringing this pest to Honduras. All of the farmers interviewed concurred that *paratrioza* is a significant problem in potato producing regions of Western Honduras. This psyllid is capable of transmitting two serious diseases, the psyllid yellow disease of potato (PY) and zebra chip disease (ZC). ZC in particular represents one of the most significant contemporary potato diseases. This psyllid is adapted to moderate temperatures, and epidemics have been associated with extended periods of cool temperatures in the region. Potatoes presenting ZC are unfit for any use. All of the potato varieties are susceptible to ZC.

Climate change impacts on potato productivity

There is high potential for a decrease in productivity of potatoes in Western Honduras due to climate change. The potato plant is susceptible to both drought and excessive water in the soil. Most vegetative stages are vulnerable to climate extremes. Reproductive stages and tuber development are more resilient to climate change. Extended rainy seasons can enhance plant development but will impact stolon and tuber filing, which will in turn, reduce yields (Hijmans, 2003; Sanabria and Lhomme, 2013).

Climate change impacts on common pests and diseases that affect potato

- **Paratrioza (Potato Psyllid)** ***Bactericera cockerelli, Paratrioza cockerelli***. There is very high potential for increased prevalence of Potato Psyllid in Western Honduras due to climate change, particularly under conditions of steady, long periods of warm (but not hot) weather. The Potato Psyllid is the causal agent of two very serious diseases of potato and, if not adequately controlled, it will impact potato production areas very seriously (Buchman, et al., 2012; Munyaneza, 2012).
- **Tizon Tardio (Potato Late Blight)** ***Phytophtora infestans***. There is very high potential for an increase in prevalence of Potato Late Blight, particularly under increased rainfall and warmer-than-normal temperature scenarios. Potato Late Blight is a very devastating potato disease capable of complete destruction of potato fields (Turner, 2005). Bellini and Provento, currently the most cultivated varieties in Western Honduras, are susceptible to Late Blight.
- **Mosca Blanca (White Fly)** ***Bermisia tabaci, Trialeurodes vaporariorum***. There is moderate to high potential for an increase in prevalence of White Fly, particularly under warmer-than-normal temperature scenarios. Feeding is responsible for virus disease transmission.
- **Virus del Enrollamiento de la Hoja de Papa (Potato Leaf Roll Virus)**. There is moderate potential for an increase in prevalence of Potato Leaf Roll Virus under decreased rainfall scenarios and warmer-than-normal temperatures, conditions that favor vectors (aphids). Moderate prevalence is expected under decreased rainfall scenarios and warmer-than-normal temperatures. Potato Leaf Roll Virus is the most serious viral disease of potatoes but can be prevented by using certified, clean seed.

Potato production system. La Esperanza, Intibuca. Photo by L. Caballero, 2014.

Lettuce

The most vulnerable stages of lettuce production occur when seedlings are transplanted to the field and are exposed to unexpected changes in weather and/or pests and diseases. Since flowering is not desired, vulnerability is greatest during vegetative phases. Water requirements in lettuce increase with the expansion of the leaf area and when the plant reaches maturity. Thickening of leaves is important in lettuce and is directly correlated with water uptake by the plant. Cool temperatures at night are also important for leaf thickening. High rates of evapotranspiration (due to high temperatures) will reduce the quality of the crop, as total biomass and dry matter will be affected by excessive water loss by the plant (Wheeler et. al., 1993). Farmers in FGDs indicated that *babosa* (slug) infestation has increased in prevalence and caused significant losses in recent years, likely due to increased humidity and excessive rainfall. In some cases, it was reported that *babosa* infestations destroyed entire fields in one night. All of the phenological states of lettuce are vulnerable to slug attacks. Another serious pest affecting lettuce production in Western Honduras is *gallina ciega* (white grubs), although this pest is more damaging if the plant is infested early in the season because it can destroy the root system.

Field visits to lettuce production sites in Western Honduras revealed effective management practices supported through technical assistance. *Belén Gualcho*, for example, has established production systems through effective seed production and efficient water use through drip irrigation and raised beds. Planting seeds in raised beds allows farmers to reduce impacts of abiotic and biotic stresses at early stages of plant development, in particular seed germination, early root development, and plant elongation. Farmers in Belen Gualcho also indicated that climate dictates the variety to be used. For example, the variety Avivan is sometimes preferred because it has enhanced tolerance to lower temperatures and waterlogged soils after heavy precipitation. Other hardy varieties used are Crispino, Salinas Super 59, and Cartagena.

Climate change impacts on lettuce productivity

There is moderate to high potential for a decrease in productivity of lettuce in Western Honduras due to climate change impacts. Since plant development is shorter than other crops, lettuce can be tracked closely for changes in climate conditions affecting growth. Excessive rain and drought will impact early stages of the plant, in particular germination and early emergence, if seeds are germinated in fields. However, the use of raised beds and greenhouses to produce transplants is common practice in Western Honduras and make lettuce less vulnerable to climate impacts in early stages of plant development.

Climate change impacts on common pests and diseases that affect lettuce

- ***Babosa, Ligosa* (slug) *Sarasinula plebeian***. There is high to very high potential for increased prevalence of *babosa*, particularly under increased rainfall and cooler-than-normal temperature scenarios. Slug attacks have increased in recent years, and higher elevations are more affected by pest development. Plants are vulnerable at all stages of development.

- ***Gallina Ciega* (white grub) *Phyllophaga spp***. There is moderate potential for increased prevalence of *gallina ciega*, particularly under increased soil humidity and cooler-than-normal temperature scenarios.

- **Nematodos (Nematodes) *Pratylenchus sp, Meloidognie sp, Radopholus spp***. There is slight potential for an increase in prevalence of nematodes, particularly under increased rainfall and cooler-than-normal temperature scenarios. Rotation is imperative to reduce nematode contamination.

Drip-irrigated lettuce, Belen Gualcho.
Photo by J. Parker, 2014.

Maize

Maize is the most important staple crop grown in Western Honduras, followed by beans. Climate can affect maize at all stages of development, but the most vulnerable stages are at germination, flowering, and physiological maturity. As maize requires soils with proper levels of humidity, early vegetative stages of breaking of seed dormancy, seed germination, elongation, and other early developmental stages are particularly vulnerable to climate impacts. In particular, extended dry periods are a serious problem for early maize plants (Tao and Zhang, 2011). For example, maize varieties with an average of 100-120 days to maturation require at least 600 to 700 mm of rain for their vegetative stages. If drought is associated with high temperatures, plants do not survive for very long. Ideal planting conditions for seed germination occur when soils have enough moisture and temperatures are in the range of 15-30 °C. It is important to note that drought or prolonged water constraints would affect all of the phenological stages of maize, both vegetative and reproductive phases. In the reproductive phase, when physiological maturity is reached, many farmers perform the practice known as "*dobla*," which consists of bending the stem to allow the cobs and grains to dry. Rain and high humidity at this stage will allow fungi to develop and will rot the corn.

Based on information gathered through FGDs, farmers in Western Honduras perceive that rains are increasingly delayed and unpredictable compared to conditions in the past, which has created problems in planting decisions. For example, May 3rd ("*Día de las Cruces*"), was previously the benchmark for the onset of the rainy season; however, farmers now indicate that rains begin in June. The agricultural calendar for maize in Western Honduras has traditionally been divided into two stages: "*primera*" in the first days of May and "*postrera*" in the first two weeks of October. Farmers have indicated that changing and more unpredictable precipitation patterns in the region have limited their ability to produce the second round of maize known as "*postrera*." Most varieties farmers use are *criollas*, which include a large number of diverse varieties that are adapted to local environments. However, the quality and productivity of these varieties are generally low (Hintze, et. al., 2003). Farmers in Tomala, Marcala, and San Antonio del Norte mentioned that varieties from other regions (e.g., coastal regions) were used at different times in the past; however, they "degenerated" after a few seasons. This degeneration likely was caused by high pest/disease pressure, limited adaptation to local conditions, and/or the loss of genetic uniformity due to open pollination. Some commercial growers use hybrid maize at a very small scale, but it requires higher inputs to obtain good yields. Breeding to produce drought-tolerant varieties was indicated in FGDs, KIIs, and secondary literature as one of the most important perceived needs in maize (Monneveux, et al., 2006).

Climate change impacts on maize productivity

There is moderate potential for decreased productivity of maize due to changes in precipitation and temperature, particularly during early vegetative stages of germination as well as emergence and seedling growth. However, maize shows remarkable adaptability in later developmental stages. There is moderate potential for a decrease in quality of maize production if the harvest is delayed and during post-harvest, especially if cobs are exposed to wet conditions and high humidity. In other phenological stages, the combination of heat and drought can significantly affect plant development. Climate projections of changes in the timing of precipitation patterns will likely force farmers to modify current planting and harvesting dates. A recent study by Schmidt et al. (2012) that analyzed the potential impacts of climate change on Central American Maize-Bean systems found that under higher temperature and lower precipitation conditions, maize and beans yields will be affected significantly with some regional variations in the levels of yield loss.

Climate change impacts on common pests and diseases that affect maize

- ***Cogollero del maíz* (Fall Armyworm) *Spodoptera Frugiperda***. There is moderate to high potential for an increase in prevalence of cogollero in Western Honduras, particularly under warmer-than-normal temperatures and decreased rainfall scenarios. Under a scenario of higher rainfall in the growing season, prevalence of cogollero in soils could be prevented. Presence of cogollero in the soil at planting will destroy young plants, particularly at the germination stage.

- ***Gallina ciega* (white grubs) *Phyllophaga spp*.** There is moderate potential for an increase in the prevalence of gallina ciega, particularly under decreased rainfall and warmer-than-normal temperature scenarios. Increased rainfall early in the season will prevent serious infestation of soils.

- *Pudrición de la Mazorca, Mazorca Muerta* (Ear Rot, Dead Cob) *Stenocarpella spp. Fusarium graminearum, Giberella zeae, Fusarioum moniliforme*. There is high potential for an increase in the prevalence of this disease, particularly under increased rainfall and warmer-than-normal temperature scenarios. Prolonged exposure to outside conditions, especially high humidity, will increase chances of ear rot and loss of crop quality.

- ***Complejo Mancha de Asfalto*, *Phyllachora maydis, Monographella maydis, Coniothirium phyllachorae*.** There is moderate potential for an increase in the prevalence of Complejo Mancha de Asfalto, particularly under increased rainfall and cooler-than-normal temperature scenarios.

- ***Virus del Achaparramiento del Maíz* (Corn Stunt) *Spiroplasma kunkelii*.** There is moderate potential for an increase in the prevalence of corn stunt, under decreased rainfall scenarios and warmer-than-normal temperatures, as these conditions favor the development of vectors.

Hillside maize production outside of Candelaria, Lempira.
Photo by J. Parker, 2012.

Beans

Beans are another important staple crop in Western Honduras. The mode of cultivation is very similar to maize in terms of agricultural practices and calendars. Planting of beans is closely associated with planting maize at the time of *primera* planting. Beans, like maize, are mainly used for household food security; only a limited amount of the harvest is used for commercial purposes. Another part of the harvest is utilized as seed for the following season. Most of the bean production (more than 50 percent) has traditionally taken place in the *postrera* season. Beans are a particularly resilient crop under the climate and agro-ecological conditions of Western Honduras. Farmers in the Western Honduras region cultivate *criolla* varieties, which are adapted to the region's conditions of poor soils, periods of drought, erratic rain, minimum agricultural inputs, and rotation of maize. However, similar to maize, these varieties produce low yields and are often susceptible to pests and diseases. Bean plants require less water than maize, though early stages of plant development are also vulnerable if drought is prolonged and heat is significant. The root system of bean plants offers a slight advantage to capture water in soils as compared to the roots of maize. Two of the most important biotic constraints to beans in Western Honduras are the *gallina ciega* (white grubs) and the *virus del mosaic* (mosaic virus). *Gallina ciega* is particularly damaging during the early stages of plant development as it can destroy the roots and prevent further development of the plant.

Most varieties cultivated are traditional varieties (Meza et al., 2013); however, farmers indicate that better varieties, in terms of pest/disease resistance and improved adaptation to local conditions, are needed. Some of the main bean varieties in Western Honduras are Lira, Tio Canela, Cuarentano, and Seda. Bean production in Western Honduras has benefitted from local breeding programs and the development of new varieties, which demonstrates that significant advances are possible in beans through simple breeding schemes (Mather et al., 2003). The improved variety Amadeus 77 was developed through the *Programa de Investigación en Frijol* (PIF) at the *Escuela Agrícola Panamericana of Zamorano* in 1995. This was a simple cross between two old varieties: Tío Canela 75 and DICTA 105. Amadeus 77 produces high yields, is well-adapted to diverse agro-ecological conditions, is heat tolerant, and offers high resistance to mosaic viruses.

Climate change impacts on bean productivity

There is a moderate potential for decreased productivity of beans due to changes in precipitation, particularly during the vegetative stages of plant initiation and emergence. Under a scenario of low moisture in the soil, beans are comparatively more resilient than other crops and can tolerate mild droughts and also mild waterlogging due to additional rainfall. Excessive rain at the times of flowering can affect pod formation and reduce yield (McClean, et. al., 2011).

Climate change impacts on common pests and diseases that affect beans

- ***Gallina Ciega* (white grubs) *Phyllophaga spp***. There is moderate potential for an increase in prevalence of *gallina ciega*, particularly under decreased rainfall and warmer-than-normal temperature scenarios. Increased rainfall early in the season will prevent serious infestation of soils.
- ***Babosa, Ligosa* (slug) *Sarasinula plebeian***. There is moderate to high potential for increased prevalence of *babosa* in Western Honduras, particularly under increased rainfall and cooler-than-normal temperature scenarios. Slug attacks have increased in the region in recent years, likely due to the increased precipitation.
- ***Gorgojo* (Dry Bean Weevil) *Zabrotes subfasciatus***. There is high potential for increased prevalence of gorgojo in Western Honduras, particularly under humid and warmer-than-normal temperature at storage. Bean weevil is highly destructive of bean grains and affects marketing.
- ***Virus Común del Mosaico* (Mosaic Virus, Bean Common Mosaic virus)**. There is high potential for an increase in prevalence of Mosaic Virus, particularly under warmer-than-normal temperatures and decreased rainfall scenarios. Bean Common Mosaic Virus is one of the most prevalent bean diseases in Western Honduras.

Farmer outside of Gracias, Lempira showing damage to bean crops from storm. Photo by J. Parker, 2014.

2.2.6 Key findings of the phenological analysis

- Based on a phenological analysis of the extent of climate impacts on the five selected crops, all crops are vulnerable to projected climate change impacts of increased temperature and reduced and more variable precipitation.
- There is moderate potential for decreased productivity of maize due to changes in precipitation and temperature, particularly during early vegetative stages of germination as well as emergence and seedling growth. However, maize shows remarkable adaptability in later developmental stages.
- Beans are comparatively more resilient than other crops and can tolerate mild droughts and additional rainfall. There is moderate potential for decreased productivity of beans due to changes in precipitation, particularly during the vegetative stages of plant initiation and emergence. There is moderate to high potential for an increase in the prevalence of common pests and diseases that affect beans due to increased temperatures and changes in precipitation.
- There is a very high potential for decreased productivity of coffee due to climate change impacts, particularly during flowering and fruit development. Changes in the timing of rain and dry periods during floral development have significant impacts on fruit and grain development. Arabica coffee responds sensitively to increasing temperatures, specifically during blossoming and fruit development. Unfavorable climatic events in early transplanting — drought, in particular— have significant impacts on coffee plants. There is a very high potential for increased prevalence of Coffee Leaf Rust, particularly under increased rainfall and warmer-than-normal temperature scenarios.
- There is high potential for a decrease in productivity of potatoes in Western Honduras due to climate change. The potato plant is susceptible to both drought and excessive water in the soil, and most vegetative stages are vulnerable to climate extremes. There is high potential for an increase in common pests and diseases that affect potatoes due to climate change impacts, particularly Potato Psyllid and Potato Late Blight.

2.3 SENSITIVITY OF SOCIAL SYSTEMS

2.3.1 Value chain analysis of the selected crops

Climate change not only affects the crop life cycle – it also directly and/or indirectly influences the entire value chain, from pre-production to post-harvest storage, marketing to transport. For this reason, additional analysis of the value chain provides a more comprehensive assessment of the effects of climate change on individual crop commodities. An analysis of the value chain examines the interrelationships and linkages between all actors that participate in the stages of the value chain – from input supply through production, processing, marketing, and end point consumption. Bottlenecks can cause inefficiencies that restrict supply, reduce profitability for producers and processors, and result in increased costs for consumers.

This value chain analysis takes the findings of the phenology study a step further by looking at how climate impacts affect various stages of the value chain for different crops. Annex 5: Value Chain Analysis presents the results of a detailed value chain analysis for the targeted crops of maize, beans, coffee, and horticulture, as well as summaries of their vulnerabilities, existing adaptation strategies, gaps, and options.

By definition, value chain approaches focus on a single commodity; however, in assessing the overall risk and impact of climate change, it is important to consider the entire livelihood and food security status of households at risk. Integrating value chains is critical to assessing the big picture of how climate change affects a particular production system to capture the potential for adaptability and environmental sustainability and ensure economic rewards for all actors. It is also essential to note that many value chain actors provide services that cut across value chains at a particular node. Additionally, different aspects of the value chain hold potential solutions to climate change risk – whether they be supplying research services, input production and distribution, extension services, diversification of agricultural production, post-harvest handling, and/or marketing expertise.

The following section briefly summarizes the results that emerged from the value chain analysis:

Coffee. Coffee is the most important cash crop in Honduras, with 106,000 producers and approximately 272,000 hectares of coffee planted (*Instituto Hondureño del Café* [IHCAFE], 2014). It is extremely important in terms of output, employment, and export earnings. For the 2011-2012 harvest, Honduras passed Guatemala as the top coffee producer in Central America, producing 3.8 million 60-kilogram bags of coffee. Honduras is the third-largest exporter of coffee in Latin America, after Brazil and Colombia, and sixth in the world. Most coffee in Honduras is produced by smallholder farmers; it is estimated that smallholders produce up to 95 percent of annual coffee production (Samayoa and Hernandez, 2013). The coffee value chain in Honduras generates more than 1.2 million jobs, which is the equivalent to approximately 30 percent of Honduras' total population (IHCAFE, 2014). Seasonal revenues from coffee harvesting are a significant source of income for poor households in Western Honduras, driving seasonal migrant-labor flows, both within Western Honduras and across borders to the areas offering the highest wages (FEWS NET, 2014). During the 2010-2011 harvest, coffee exports represented 40 percent of all agricultural exports and sales contributed to 27 percent of the country's agricultural gross domestic product (United States Department of Agriculture [USDA], 2012). Western Honduras is a critically important coffee growing region in Honduras, as it produces 58 percent of total production. Most coffee from the Western Region is produced in the departments of Copán (23 percent), Santa Barbara (22 percent), Lempira (20 percent), Ocotopeque (14 percent), and La Paz (13 percent) (IHCAFE, 2014). There are strong opportunities for expanding the specialty coffee market share in Western Honduras. Eighty percent of the coffee in the Western highlands meets requirements for specialty coffee; however, only 10 percent is formally sold under this designation (Feed the Future, 2011).

Because coffee is an internationally traded commodity, the coffee value chain in Western Honduras is a complex network involving a large number of actors operating at national and international levels, including producers, pickers, intermediaries, processors, coffee roasters, distributors, exporters, and importers. The complexity and scale of this network means that climate shocks and stresses — both within and outside of Honduras — have the potential to produce significant impacts that reverberate across the value chain and affect all actors resulting in major impacts on the overall Honduran economy. For example, the impacts of Coffee Leaf Rust on coffee production in 2012-2013 resulted in economic losses totaling approximately $216 million (Rock, 2013). In 2014, FEWS NET (2014) has reported that poor households in Western Honduras have resorted to atypical, negative coping strategies as reduced coffee harvests and below-average Primera staple grain production have limited their income and food stocks. In addition, price fluctuations in global Arabica coffee prices, which have decreased by almost 60 percent since their high in April 2011, have also significantly affected household incomes of producers in Western Honduras. FEWS NET (2014) reports that daily unskilled labor opportunities in Honduras are expected to decrease by between 16 and 32 percent compared to 2011-2012 due to the effects of the Coffee Leaf Rust. These events indicate how sensitive the coffee value chain is to climate-related shocks and the magnitude of impacts on livelihoods and the economy.

Maize and beans. Maize is the major staple crop of Honduras. About 75-80 percent of annual production takes place during the first season, with the bulk of the harvest in October and November. In Western Honduras, most maize is produced on smallholder farms with less than 2.5 hectares and is grown mainly for household food security. Production of beans in Western Honduras is mainly for household food security needs (FEWS NET, 2013). Between 65 and 75 percent of annual production is obtained during the second season crop, harvested from November to mid-March. Depending on the season and on local food availability, maize and beans in Western Honduras are informally exported to El Salvador (WFP, 2005). The main food markets for maize and beans in Western Honduras are La Esperanza, Gracias, Santa Rosa de Copán, and Nueva Ocotopeque. At the local level, food markets for maize and beans are quite fragmented, serving the local population with local production. Many local markets in Western Honduras have limited linkages with principal regional markets due to inadequate road infrastructure. In general, farmers in Western Honduras with surpluses in maize and bean production sell to local village stores, rural wholesalers, and regional intermediaries. The majority of sales are made to regional intermediaries that buy production in communities, particularly in more remote areas with difficult access to markets (World Food Programme [WFP], 2005). The impacts of the 2014 El Niño provide an indication of how climate-related shocks affect the maize and bean value chains in Western Honduras. Irregular and delayed rains have negatively affected maize and bean production in the region, significantly driving up prices, particularly for beans. In response, the government is importing beans through the National Commodity Supplier (BANASUPRO) in an attempt to stabilize prices. If these actions do not reduce hoarding behavior, the government is considering plans to freeze bean prices in local markets and supermarkets (FEWS NET, 2014). Studies of previous climate-related shocks in Western Honduras have found that affected households tend to shift consumption patterns due to price impacts or reduced food availability. For example, after Hurricane Mitch, bean seeds were more affected than maize, so farmers temporarily switched consumption to maize (de Barbentane Nagoda and Fowler, 2003).

Horticulture. Vegetable and fruit production in Western Honduras is growing as national, regional, and international market opportunities expand. Horticulture production represents an opportunity for diversification of livelihoods in Western Honduras beyond subsistence production of maize and beans. There are essentially three types of vegetable producers in Honduras: 1) household producers, mainly women, who produce vegetables and fruit in family gardens; 2) emerging producers who sell their surplus in informal markets; and 3) advanced producers that belong to producer organizations and have established market connections. The main stages of the horticulture value chain include production, storage, trading, and marketing. The rise of supermarkets in Western Honduras is creating new market opportunities for fresh produce; however, traditional local markets and processing buyers still represent the main market opportunities for horticulture producers in Western Honduras. While horticulture production presents an option for livelihoods diversification, it is also particularly vulnerable to climate change, as documented by the phenological analysis. Two of the principal vegetable crops grown in Western Honduras, lettuce and potatoes, have high potential for decreased productivity due to increased temperature changes and precipitation variability. There are significant climate risks and vulnerabilities associated with the marketing, transport, and export stages of the horticulture value chain, as demonstrated in Table 9.

Table 8 presents key comparisons between the selected commodities based on an analysis of secondary literature, including government documents, technical reports, peer-reviewed literature, KIIs with representatives of key institutions involved in agriculture in Western Honduras, and FGDs with farmers and institutions in eight municipalities. The table compares five crop value chains relative to level of importance for livelihoods, food security, and country strategy (strategic priority); integration and commercialization of value chains; and vulnerability to disease and climate. In terms of importance, coffee ranks high in terms of national importance and livelihoods but low for food security. Maize and beans rank high for food security, livelihoods, and strategic priority, but low for level of integration and commercialization of value chain. Potato ranks high for strategic priority but medium for food security and livelihoods. Lettuce ranks medium for strategic priority and low for food security and livelihoods. In terms of vulnerability to disease and climate, coffee and potato are highly vulnerable to both; lettuce ranks high to medium; maize ranks medium; and beans ranks low.

TABLE 8. OVERALL COMMODITY COMPARISON

	Coffee	Maize	Beans	Potato	Lettuce
Level of Strategic Priority	High	High	High	High	Med
Importance for Food Security	High	High	High	Med	Low
Importance for Livelihoods	High	High	Low	Med	Low
Level of Integration and Commercialization of Value Chain	High	Low	Low	Med	Med
Vulnerability to Disease	High	Med	Low	High	High
Vulnerability to Climate	High	Med	Low	High	Med

Detailed analyses of value chains in Western Honduras for coffee, maize, beans, and horticulture is provided in Annex 5: Value Chain Analysis. Based on this analysis, below, for each crop value chain, is a summary of key climate-related risks and vulnerabilities at different stages of the value chain. The findings are based on a review of secondary literature (government documents, data and reports from IHCAFE, peer-reviewed literature, project reports, etc.), supplemented by KIIs with representatives of key institutions involved in coffee production in Western Honduras as well as FGDs with farmers. These findings were subsequently presented for stakeholder feedback during validation workshops with key institutions in FGD sites. Annex 5 provides more detailed information on the climate-related risks and vulnerabilities of different stages of the value chain.

TABLE 9. COMPARISON OF THE EXTENT OF CLIMATE-RELATED RISK AND VULNERABILITY BY CROP VALUE CHAIN

Value Chain Stage	Vulnerability	Coffee	Maize	Beans	Potato	Lettuce
Production	Rising temperature threatens suitability for production	++	+++	+++	++	++
	Falling soil fertility reduces yields and makes crop more vulnerable to climatic stresses	++	+++	+++	+++	+
	Poor moisture retention capacity of soils increases vulnerability to precipitation variability	++	+++	+++	++	+
	Pests and diseases increasing with rising temperatures	+++	+++	+++	+++	+++
	Shortages of disease-free planting material, exacerbated by unreliable precipitation	++	+++	+++	+++	0
Marketing and Value Addition	High temperatures and unseasonable rain promote rapid spoilage and threaten quality	+++	++	+	+++	+++
	Climate-related events reduce supply and affect local prices	+++	+++	+++	+++	+
Transport	Extreme precipitation events and flooding affect the state of the roads. Communities without access to roads. Transport is more costly and difficult.	++	+	+	++	+++
Export	International prices increasingly volatile as a result of climate change impacts on supply	+++	0	0	0	++
	Rising international concern over carbon footprint threatens demand for exports	+++	0	0	0	+++
	High temperatures and unseasonable rain affect quality and threaten ability to meet export standards	+++	0	0	+	+++

Key: *Relative impact of climate change on various aspects of vulnerability by crop:*
+++ *Highly vulnerable; ++ Moderately vulnerable; + Limited vulnerability; 0 Not Affected*

2.3.2 Sensitivity of livelihoods to climate change

The livelihood analysis is based on secondary data and information gathered at the field level through FGDs. This section builds upon the results of the value chains analysis as well as the ecosystems and crop analyses, since the relative dependence on specific crops and ecosystem goods and services determines the impact of exposure to climate change on livelihoods. In the context of livelihoods, sensitivity is defined as the impact on livelihoods of exposure to climate change and variability. In Western Honduras, the relationship between exposure and livelihoods sensitivity is complex. As discussed in previous sections, climate change affects ecological conditions, which in turn affect ecosystem goods and services and crop productivity. This effect, in turn, affects the livelihood systems that grow those crops and depend on those goods and services – particularly in Western Honduras, as most households in the region derive their livelihoods from agriculture and natural resources. Livelihood impacts from exposure to climate variability can occur through longer-term stresses such as changes in moisture availability and variations in plant species composition, or short-term shocks, such as extreme storm events. Livelihoods most vulnerable to the exposure from these climate-related events are those that are unable to absorb and withstand immediate impacts and “bounce back” without irreversible damage to the livelihood system.

To assess the differentiated sensitivity of livelihoods in Western Honduras to climate change, this section begins by providing an overview of basic demographic and socioeconomic conditions in Western Honduras by department, followed by an analysis of qualitative information on livelihoods gathered through FGDs in sites within selected sub-watersheds as well as a discussion of direct and indirect impacts of climate change and variability on the principal livelihood systems in the region. The section concludes by integrating social vulnerability indicators into the eco-hydrological vulnerability index for the selected sub-watersheds in order to create an overall social-ecological vulnerability index.

Basic demographic and socioeconomic conditions in Western Honduras

Western Honduras has six departments with a total of 19,827 km^2 representing approximately 18 percent of the country. Approximately 1.7 million people, of which 1 million are classified as extremely poor, reside in the region. The region’s natural resources have been under increasing pressure due to relatively high population growth rates (2.2 percent per year) during the past 14 years, which has led to a relatively high population density of 87 people per km^2, as compared to the national average of 74 people per km^2. The department of Copán has the highest population density with 115 people per km^2, while Intibucá and Lempira have the lowest with 74 and 75 people per km^2, respectively (Table 10).

TABLE 10. BASIC DEMOGRAPHIC AND SOCIOECONOMIC CONDITIONS FOR WESTERN HONDURAS

Department Name	Area (km^2)	Population (2001)	Estimated Population (2013)	Pop. Density (people/km^2)	HDI (2009)	MPI	
						(2001)	(2009)
La Paz	2,525	156,560	201,540	80	0.635	0.62	0.42
Santa Barbara	5,013	342,054	440,326	88	0.623	0.57	0.43
Copan	3,240	288,766	371,728	115	0.616	0.59	0.46
Ocotepeque	1,636	108,029	139,066	85	0.615	0.57	0.48
Intibucá	3,127	179,862	231,536	74	0.601	0.65	0.56
Lempira	4,286	250,067	321,911	75	0.587	0.67	0.61
Total	19,827	826,724	1,064,242	87	0.613	0.61	0.49

Note: Population estimates 2013 based on actual growth rates from 2000 to 2010. Source: World Population Review. Landcover/landuse based on Modis data Landcover classification Rivera, et al., 2009. Multidimensional Poverty Index (MPI), United Nations Development Programme (UNPD), 2014.

Socioeconomic conditions in Western Honduras present high levels of sensitivity to climate exposure due to conditions of extreme poverty, malnutrition, lack of good road access, and relatively long distance (travel time) to consumer markets (International Food Policy Research Institute [IFPRI], 2013). Poverty is widespread across the region; all departments in Western Honduras have higher poverty rates than the national average. Intibucá and Lempira are the departments with the highest percentages of people living in poverty, 56 and 61 percent, respectively. Departments in the Western Honduras region also present the greatest incidence of chronic malnutrition among children. Almost half of children are chronically malnourished in the departments of Lempira and Intibucá (48 percent each), followed by La Paz with 39 percent and Copán with 31 percent.

IFPRI's baseline household survey conducted for the USAID ACCESO project found that 95 percent of the households in the sample depend on wood as their primary fuel source (IFPRI, 2013). Nearly 30 percent of the sample did not have access to potable water (IFPRI, 2013).

Based on 2012 Human Development Index (HDI)[14] data, the average HDI level for the Western Honduras region is 0.613, which is slightly lower than the national average of 0.632 (UNDP, 2013). When comparing HDI by department, five of six departments are slightly below the national average of 0.632, with La Paz being the only one with an HDI that is slightly higher than the national average. This difference is possibly due to the fact that La Paz has a long tradition of high-quality specialty coffee production, and most coffee farming communities are well connected by road to Marcala and Jesus de Otoro – the main economic hubs for the area.

Remittances play an important role for household income and food security for many families in Western Honduras, representing between 25 and 60 percent of household incomes (ACDI-VOCA, 2013). The southern part of La Paz, although more deprived of economic opportunities, is positively influenced by remittances (ACDI-VOCA, 2013). Lempira and Intibucá have also a strong influence of remittances on their economy; however, livelihoods in these departments predominantly depend on basic grain production. KIIs and FGDs indicated that transfers tend to increase after the occurrence of natural disasters, which highlights the role of remittances as a coping strategy for households in response to climate-related shocks.

The lack of a well-maintained road network makes it more difficult for agricultural products to reach markets and bring competitive prices. Lempira and Intibucá have road access that is very limited in their southern regions, and time to markets is greater than six hours, which significantly affects any business-oriented development linked to agriculture (IFPRI, 2013). This is demonstrated by Figure 24, which presents an analysis of time for households in Western Honduras to access the nearest market centers, based on the results of IFPRI's baseline household survey conducted for the USAID ACCESO project (IFPRI, 2013). Participants in FGDs indicated that heavy precipitation events regularly affect transportation and increase time to access markets.

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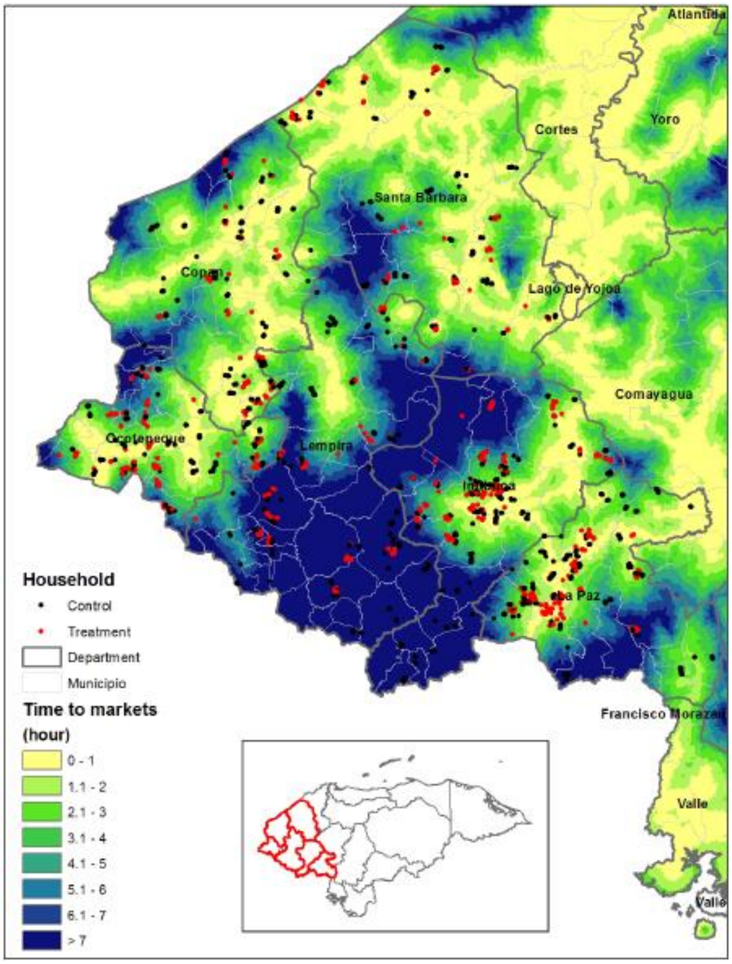
[14] The UNDP HDI, or *Índice de Desarrollo Humano* (IDH) in Spanish, is a composite indicator with three dimensions: education, health, and income. According to the UNDP, the HDI is designed "to serve as a frame of reference for both social and economic development" (UNDP, 2013a). For health, the quantitative indicator is life expectancy at birth. For education, two quantitative indicators are used: mean of years of schooling for adults aged 25 years, and expected years of schooling for children just reaching school age. The standard of living component is measured by gross national income per capita. The HDI sets a minimum and a maximum for each dimension, called "goalposts," and then shows where a given population stands in relation to these goalposts, expressed as a value between 0 and 1.

FIGURE 24. ANALYSIS OF TIME FOR HOUSEHOLDS IN WESTERN HONDURAS TO ACCESS NEAREST MARKET CENTERS



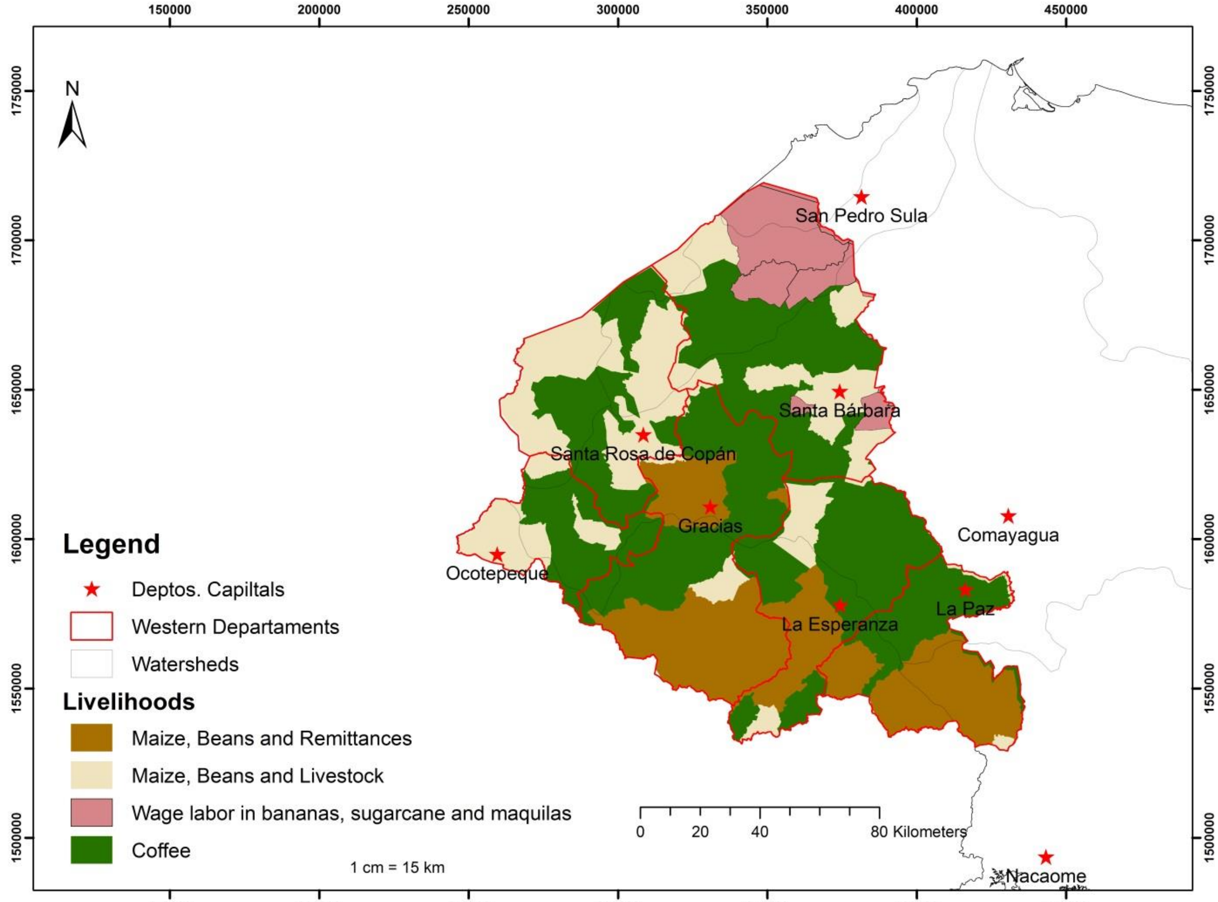
Livelihood profiles of Western Honduras

According to the most recent census data, men aged 15-49 from departments in Western Honduras are predominantly engaged in agriculture for their livelihoods (INE, 2013). These percentages range from 50 percent in Santa Barbara to 82.7 percent in Lempira, with an average of 67 percent across the six departments in the region. Women also are heavily engaged in agriculture, ranging from 17.3 percent in Santa Barbara to 45.2 percent in Lempira. IFPRI (2014) assessed women's empowerment in Western Honduras, applying the Women's Empowerment in Agriculture Index (WEIA), which is a composite measurement tool that indicates women's control over critical parts of the lives in the household, community, and economy. The analysis revealed that 68.5 percent of the women in the sample were classified as disempowered, in comparison to 39.9 percent of the males. The WEIA also calculated the level of inequality within dual households through a Gender Parity Index. Fifty-eight percent of dual households in the sample were classified as gender parity-inadequate.

Secondary literature and information gathered from FGDs identify maize and beans, and to a lesser extent sorghum, as the principal basic grains that households grow for food and nutrition security. The crop that is most economically profitable and moves the local economy is coffee, followed by horticultural crops, notably lettuce and potato. Figure 25 displays the main livelihood zones in Western

Honduras by geographic area, divided into four livelihood zones: maize, beans, and remittances; maize, beans, and livestock; wage labor; and coffee (FEWS NET, 2014).

FIGURE 25. LIVELIHOOD ZONES IN WESTERN HONDURAS



FGDs carried out in eight sites within five sub-watersheds gathered information on livelihood profiles within each site and sub-watershed, as presented in Table 11. The table lists the principal livelihood activities in each site, as perceived by FGD participants, who represented both key institutions and farmers. The livelihood in bold was considered the most important within each site. This information substantiates secondary data that coffee, maize and beans, and to a lesser extent, horticultural production, represent the predominant livelihood activities within the Western Honduras region.

TABLE 11. LIVELIHOODS BY SUB-WATERSHED

Municipality	Department	Sub-Watershed	Livelihoods
La Florida, Opatoro	La Paz	Upper Palagua-Goascorán	**Coffee, maize, beans**, household fruit production (orange, mango, lemon, avocado, banana, sapote, annona)
San Antonio del Norte	La Paz	Lower Palagua-Goascoran	**Maize, beans, and sorghum** Cattle production Sale of services (food, mechanic, carpentry, welding, masonry, transportation) Sand and rock extraction for construction Construction and sale of tiles and blocks Forest products (firewood, wood for roofs) Remittances
La Esperanza	Intibucá	Upper El Venado-Lempa	**Coffee, maize, beans, potato**, cabbage, lettuce, broccoli, carrots, cauliflower Agricultural trade Cattle production Forest products (pine, encino, roble, charcoal production) Tourism and handicrafts
Marcala	La Paz	Upper Río Grande de Otoro	**Coffee** Transport services Microfinance Remittances Maize and beans Cattle production Microenterprises Professional services for the government and projects Construction
Jesús de Otoro	Intibucá	Lower Río Grande de Otoro	**Rice, coffee**, maize and beans, horticultural crops (tomato, chile, watermelon) Remittances Cattle production Forestry Frutales Carpentry, microenterprises, informal trade
Belén Gualcho	Ocotepeque	Upper Mocal-Lempa	**Horticultural crops, coffee**, maize and beans, trade (agricultural inputs, food)
Tomalá	Lempira	Lower Mocal-Lempa	**Maize and beans**, coffee Cattle production Tule cultivation Soap Dulce de panela
San Marcos	Ocotepeque	Upper Higuito-Ulua	**Coffee**, horticultural crops, maize and beans Sand and rock extraction for construction, beekeeping, cattle production, agribusiness, recycling, rural tourism Fruit production (pineapple, plantains, avocado) Brickmaking

Climate change impacts on livelihoods

FGDs were conducted to identify detailed farmer and institutional perceptions of the impacts of climate variability and change on livelihoods. Farmers perceive that climate has had a major impact on their livelihoods. During the past 20 years, farmers identified three principal climate-related trends occurring in the region:

- **Unpredictable rainfall**. Farmers perceive that the onset of the rainy season and the length of the growing season are unreliable, and the start and duration of the *canícula* is no longer predictable.
- **Temperature variability and extremes**. Farmers perceive that there is an overall increase in temperature in the region and more extreme temperature variations.
- **Severe weather events**. Farmers perceive that there are heavier rain events now than in the past, but these are of shorter duration. In addition, there are stronger winds and more severe hailstorm events.

These perceptions are largely substantiated by the climate analysis (Section 2.1), which identified increased but sustained high temperatures and an intensification of rainfall rates across some of the region. The direct impact of these climate-related trends and events as perceived by farmers include an overall decrease in crop productivity and yield; loss of crops due to strong rainstorms, temperature fluctuations (particularly with horticultural crops), late onset of the rainy season, and absence of the *canícula* (affecting maize and beans, in particular); and increased incidence of plagues and disease. Below we outline the potential impacts of the sensitivity of livelihoods in Western Honduras to climate change and variability.

According to the IPCC predictions for Western Honduras as described in the Climate Analysis in Section 2.1, Western Honduras could experience 2 °C of warming and a net change in precipitation of between -10 percent to -20 percent by 2050. By mid-century Western Honduras is likely to become a “hotspot” of magnified climate change related stress. Taking this scenario into account, below we discuss potential direct and indirect impacts of these changes in climate on main livelihood systems in the region.

Maize and beans. For basic grain production, which occurs throughout the Western Honduras region, as climate impacts affect yield of maize and beans, this creates indirect effects on livelihoods through increased cereal prices, cost of feed, and increased prices of meat. This, in turn, will decrease household consumption of cereals and reduce meat consumption. Reduced and rising local commodity prices would reduce all elements of household food security (access, availability, and utilization), which would negatively affect nutrition security for households, particularly for children. A situation of reduced household food security due to climate-related impacts could contribute to increased crime due to theft of crops.

Coffee. As previously discussed, coffee is considered highly vulnerable to climate change and variability, both in terms of its phenological stages and the coffee value chain, thereby creating high levels of vulnerability for the many households in Western Honduras that depend on coffee production for their livelihoods. As climate change and variability affects quality and quantity of coffee, it will decrease household income for coffee producers, which in turn will reduce household food access (the affordability and allocation of food, as well as preferences of individuals and households). As many households that engage in the coffee sector work as wage laborers, the drop-off in demand would compromise the ability of these households to meet their food needs. The impacts of lower quality and quantity of coffee would have reverberations well beyond coffee producers and wage laborers, as they would affect employment and income generation across the many actors that make up the coffee value chain. These impacts would, in turn, negatively affect both the local and national economy of Honduras and reduce exports, thereby generating less revenue for the government.

Horticulture. Increased temperatures and precipitation variability and extremes will decrease productivity of horticulture in Western Honduras. This trend, combined with the high irrigation demand of many horticultural crops, would likely reduce the large-scale viability of horticulture as a livelihoods diversification option across the region. Climate impacts on horticulture production will negatively affect employment in horticultural production regions of Western Honduras. As horticultural producers and wage laborers in Western Honduras are more prone to out-migration when employment options are limited, reduction of horticulture production due to climate change and variability could create a scenario of increased out-migration to urban areas and, in particular, to the United States.

2.3.3 Key findings of livelihoods analysis

- Socioeconomic conditions in Western Honduras present high levels of sensitivity to climate exposure, characterized by extreme poverty, malnutrition, lack of good road access, and poor access to consumer markets.
- Livelihoods in Western Honduras are also highly sensitive to climate impacts, as they predominantly depend on agriculture, particularly maize and beans, coffee and, to a lesser extent, horticultural crops.
- Farmers perceive that climate has had a major impact on their livelihoods during the past 20 years primarily due to unpredictable rainfall, more extreme temperature variations, and heavier rain events of shorter duration.
- Farmers perceive that the main direct impacts of these climate-related events on their livelihoods include decreased crop productivity, loss of crops, and increased incidence of pests and diseases.
- As coffee is the most sensitive commodity to climate change, livelihoods that depend on coffee production — not just producers, but actors across the entire value chain — will likely be most affected by climate impacts.
- Climate impacts on livelihoods that depend on maize and bean production will be directly affected by impacts on productivity, and indirectly affected by increased prices, cost of feed, and price of meat, which will reduce all elements of household food security.
- Climate change will likely decrease the productivity of horticulture, which combined with the high irrigation demand of many horticultural crops, would likely reduce the large-scale viability of horticulture production across the region. Increased out-migration to urban areas and the United States may occur, as employment options for horticultural producers and wage laborers are limited.
- Expanding upon the eco-hydrological vulnerability index, key social variables (population density, poverty levels, and HDI) are integrated into the analysis to present an overall social-ecological vulnerability of the selected sub-watersheds. Based on this analysis, Venado-Lempa is by far the most social-ecologically vulnerable to climate exposure, followed by San Juan-Lempa, Higuito, and Mocal-Lempa. The least social-ecologically vulnerable sub-watershed is Grande de Otoro.

2.3.4 Social-ecological vulnerability of selected sub-watersheds

To expand upon the eco-hydrological vulnerability analysis of the selected sub-watersheds (as detailed in Section 2.2.2), we integrate key social variables (population density, poverty level, and HDI) to present an overall social-ecological vulnerability index for the selected sub-watersheds.

Population density for each watershed was estimated for 2013 using 2001 municipal-level census data and a 2.25-percent growth rate per year (World Population Review). For each sub-watershed, the proportion of area that each municipality shared within the sub-watershed was calculated and multiplied by the estimated 2013 municipal-level population. This result provides the relative contribution of each municipality to the total estimated sub-watershed population. The estimated sub-watershed population was then divided by sub-watershed area to calculate population density. The poverty index was calculated as an average of all municipalities sharing part of the sub-watershed.

We assumed that population density and poverty index have a negative effect on sub-watershed vulnerability; in other words, higher values contribute to increased vulnerability. For the HDI, it was assumed that higher HDI levels (e.g., better education, health, and income) contribute to decreased vulnerability, as people are better equipped with socioeconomic resources to withstand and recover from climate-induced shocks (e.g., drought and flooding) and they can invest these resources in capital improvements that will reduce their vulnerability (e.g., plant trees on hillsides and relocate to areas less prone to flooding).

Therefore, the product of population density and poverty index was divided by HDI to calculate the social vulnerability of each sub-watershed. More specifically, a sub-watershed with high population density, high poverty index, and low HDI would be the most socially vulnerable based on demographic and socioeconomic conditions.

To calculate the overall social-ecological vulnerability of the sub-watersheds, we divided the social vulnerability index by the eco-hydrological index. Table 12 presents the results of the social-ecological vulnerability of each sub-watershed based on these variables. Based on these results, the sub-watersheds are then ranked in terms of overall social-ecological vulnerability to climate change, with 1 being the most social-ecologically vulnerable and 8 being the least.

TABLE 12. SOCIAL-ECOLOGICAL VULNERABILITY INDEX OF SELECTED SUB-WATERSHEDS

	Social Vulnerability (÷)			**Ecological Vulnerability**		**=**	
Sub-watershed	**Pop. Density (P/km^2)**	**Poverty Index**	**HDI**	**PLCI**	**Water Production Potential (Hm^3/km^2)**	**Social-Ecological Vulnerability Index**	**Social-Ecological Vulnerability Ranking**
Palagua-Goascoran	43	0.405	0.635	0.72	0.15	254	6
San Juan-Lempa	58	0.454	0.576	0.67	0.14	487	2
Higuito	90	0.331	0.610	0.55	0.21	422	3
Gualcarque	82	0.399	0.623	0.64	0.44	186	7
Mocal-Lempa	66	0.461	0.587	0.45	0.32	360	4
Mejocote	68	0.474	0.596	0.78	0.24	289	5
Venado-Lempa	79	0.446	0.620	0.65	0.12	729	1
Grande de Otoro	97	0.402	0.647	0.80	0.44	171	8

The results of this analysis indicate that the Venado-Lempa sub-watershed is by far the most social-ecologically vulnerable to climate exposure, followed by San Juan-Lempa, Higuito, and Mocal-Lempa. Venado-Lempa has high population density, relatively high levels of poverty, and the lowest water production potential of the selected sub-watersheds. Under climate projections of increased temperatures and reduced precipitation, Venado-Lempa will likely experience conditions of extreme water stress (due to the sub-watershed's very limited water production potential and high population density), while social systems will have limited ability to withstand and adapt to these impacts due to high incidence of poverty. A similar scenario is possible in San Juan-Lempa, which also has higher levels of poverty and very low water production potential. While Higuito has the lowest poverty rates of the selected sub-watersheds, it has among the highest population density and among the lowest permanent land cover of the sub-watersheds. The combination of high population density and low permanent land cover in Higuito means that the resource base in the sub-watershed is under significant stress that will be further exacerbated by climate impacts. More intense precipitation events, in particular, could cause significant social and ecological impacts in Higuito due to its low permanent land cover and high population density. Mocal-Lempa has relatively high levels of poverty, among the lowest HDI levels, and the lowest PLCI of the sub-watersheds. Consequently, communities in Mocal-Lempa have limited ability to withstand climate impacts due to high levels of poverty and limited social and economic development, while its ecological systems are highly sensitive to climate exposure due to the sub-watershed's low permanent land cover.

While all sub-watersheds are vulnerable to higher temperatures as well as reduced and more variable precipitation, the least vulnerable sub-watershed based on these results is Grande de Otoro, followed by Gualcarque and Palagua-Goascoran. While Grande de Otoro has the highest population density of the selected sub-watersheds, it has relatively lower poverty rates and the highest levels of HDI of the sub-watersheds in addition to the highest PLCI and water production potential. Consequently, communities in the sub-watershed are likely more capable of withstanding climate impacts due to improved livelihood conditions, while high levels of permanent land cover and water production potential indicate that its ecological systems can more effectively buffer the impacts of higher temperatures and reduced precipitation.

2.4 ADAPTIVE CAPACITY

Adaptive capacity can be defined as the ability of people and institutions in to anticipate, withstand, and respond to climate change and variability, as well as to minimize, cope with, and recover from climate-related impacts. Individuals and communities with high adaptive capacity have less vulnerability and are able to more effectively withstand and respond to climate shocks and stresses. Local institutions facilitate and improve the ability of individuals, communities, and natural ecosystems to adapt to climate change. This section assesses the adaptive capacity of farmers and institutions in Western Honduras to adjust to changes in the natural system due to climate change and variability.

2.4.1 Adaptive capacity of farmers

FGDs with farmers identified adaptive responses that have been carried out to adjust to changes that have affected agriculture over time (both climate- and non-climate-related). Climate played a direct and indirect role within many of these drivers of change, particularly related to linkages between climate exposure and land degradation and increased soil moisture evaporation, pest/disease proliferation, and declining water availability. Based on a frequency analysis of responses from farmers participating in FGDs, Table 13 below identifies adaptive practices of farmers, which were adopted largely, or in part, due to climate-related factors. The table also lists their frequency of adoption. While farmers are implementing some important adaptive practices, it is clear that the pace of adoption and innovation of adaptive practices does not meet the scale of the challenge of climate change. Some important adaptive practices have achieved large-scale adoption, such as the use of metal silos for post-harvest storage of maize, which has greatly reduced post-harvest losses. However, there has been limited adoption of natural resources management practices, particularly soil and water management, which are critical for building on-farm resilience to both droughts and heavy precipitation events. Farmers in FGDs revealed that insecure land tenure and a lack of technical assistance are significant factors inhibiting more widespread adoption of these practices. Farmers without secure access to land have limited incentive to invest in longer-term natural resource management investments.

TABLE 13. ADAPTIVE PRACTICES AND THEIR FREQUENCY OF ADOPTION

Adaptive Practices	Frequency of Adoption
Selection and adoption of local varieties that are more resistant to drought and pests/diseases	+++
Adoption of drip irrigation	+
Adoption of "*cero quema*" to address issues of soil erosion and land degradation	+
Shifting of planting dates; no longer does planting occur on May 3rd (as it did previously) – it now takes place in June or July	+++
Adoption of metal silos for post-harvest storage of maize	+++
Diversification of livelihoods both within and outside of agriculture	+
Higher density planting for maize, beans, and coffee	+++
Soil conservation (contour lines, planting against the slope, live barriers)	+
No-till systems	++
Creation of and participation in *cajas rurales*	+++
Protected agriculture (use of greenhouses, etc.)	+
Participatory investigation, farmer-to-farmer, to identify and learn management practices that reduce impacts of drought and heavy-precipitation events	+
Migration	++
Creation of local emergency committees (CODELES)	+++
Community grain storage	+
Agroforestry systems	+
Key: +: less frequently adopted ++: somewhat frequently adopted +++: widely adopted	

There are several principal sources of innovation and diffusion of these adaptive practices. Farmers highlighted three major sources of innovation: 1) farmer experimentation; 2) NGOs; and 3) private companies.

- **Farmer experimentation.** Farmers cited their own experimentation as a key source of innovation for adaptive practices, particularly for the selection of local varieties that are more resistant to climate-related factors as well as planting decisions and techniques. In addition to their individual experimentation, farmers often viewed the practices of neighbors and then made decisions to adopt certain varieties, planting techniques, and management practices based on the success (or failure) of these practices on neighbors' plots.

- **NGOs.** To varying degrees, NGOs provide technical assistance throughout Western Honduras. For example, Belén Gualcho has received intensive and sustained technical assistance in horticulture for many years, while Tomalá has received considerably less outside assistance. Farmers identified external technical assistance as a key factor in the introduction of practices that have helped buffer impacts of climate-related stresses and shocks, particularly the introduction of new and improved varieties; management practices (e.g., soil conservation and agroforestry); pest management; and the adoption of agricultural inputs (e.g., pesticides and fertilizers). Despite the overall positive impact of external technical assistance, farmers cited issues with NGO extensionists, particularly those coming from outside the region, often lacking familiarity with the agro-ecological context of specific regions and promoting management practices and varieties that are not suitable and adapted to the local context. FGDs with farmers identified that there is an overall lack of technical assistance provided to farmers, particularly related to on-farm land and water management practices.

- **Private companies.** Farmers, particularly with larger, more business-oriented operations, cited private companies as an important source of innovation for seed and improved varieties; information on the timing and application of agricultural inputs (e.g., fertilizers and pesticides); access to markets; and mechanized equipment to increase efficiency of farming operations.

Drip-irrigated lettuce in Belen Gualcho. Photo by L. Caballero, 2014.

The principal sources of diffusion of technologies and practices cited by farmers include, not surprisingly, farmer-to-farmer, NGO-farmer, and private companies-farmer. Farmers in FGDs identified farmer-to-farmer diffusion of knowledge and information on adaptive practices as most instrumental in facilitating widespread adoption of practices that reduce impacts of climate-related shocks and stresses.

Perhaps the most successful adaptive practice in Western Honduras is the Quesungual Slash-and-Mulch Agroforestry System (QSMAS), which is an integrated land and water management innovation that provides an alternative to slash-and-burn agriculture and is based on planting maize, sorghum, and beans under a zero-tillage, slash-and-mulch technique (Fernandez et al., 2005). It has been reported that more than 5,000 farmers in southwestern Honduras have adopted QSMAS, with the greatest concentration in the southern Lempira department in the municipalities of Candelaria, Mapulaca, Tomalá, and Tambla in southwestern Honduras (Ayarza and Welchez, 2008). In the 1980s, as part of the Lempira Sur Program, FAO extensionists discovered that farmers in the village of Quesungual practiced a slash-and-mulch technique rather than the traditional practice of burning vegetation that is cut after clearing. This technique allowed for organic material to decompose, which effectively conserved soil moisture ("green water") while also adding nutrients to the soil. Farmers in the village of Quesungual also practiced intercropping of trees within the system. This practice helped to reduce soil erosion, which was (and continues to be) a significant problem for hillside agro-ecosystems in Western Honduras. The effectiveness of QSMAS was enhanced by repeated on-farm trials and mutual sharing of agricultural knowledge and information between extension agents and local farmers.

Adopter of QSMAS demonstrating organic material in soil outside of Candelaria, Lempira. Photo by J. Parker, 2012.

Farms in which QSMAS has been adopted have shown a 100-percent increase in crop yields, with maize yields increasing by 1,300 kg/ha and bean yields by 475 kg/ha (Castro et al., 2009). QSMAS has also proven to be highly resilient to climate variability and shocks, enabling crops to withstand extended periods of drought as well as heavy precipitation events. During the extreme weather events of the El Niño drought in 1997 and severe flooding during Hurricane Mitch in 1998, significantly less crop losses were reported by farmers growing crops under QSMAS (Ayarza and Welchez, 2008). The system's resilience is primarily due to its permanent soil cover, which increases soil moisture retention during extended drought periods while also reducing the impact of heavy rains on crops. QSMAS is an excellent example of adaptive practices that can be resilient to climate-related shocks and stresses while simultaneously increasing agricultural productivity and improving farmers' livelihoods.

Research on QSMAS has shown that in municipalities with high adoption rates of QSMAS, farmers had secure land tenure, actively participated in community groups, and had received technical assistance (Parker, 2011). Farmers that had not received technical assistance in communities with high adoption rates eventually adopted the innovation after observing the benefits on their neighbors' farms. Another common aspect of communities with high adoption rates was that a large, heterogeneous group of actors — including international organizations, government line ministries, extension agents, NGOs, municipal governments, community groups, and farmers — collectively promoted the innovation. Local champions within local institutions, especially within municipal governments and community groups, played a particularly active role in promoting the innovation and providing incentives for adoption – both "carrots" in the form of municipal ordinances imposing a fine on farmers who practiced burning and "sticks" in the form of direct technical assistance to farmers who adopted the innovation. On the other hand, in communities with low levels of adoption, land tenure was insecure, participation in community groups was low, and fewer farmers had received technical assistance. Unlike areas with high adoption rates, a much smaller and more heterogeneous network of actors promoted the innovation, and local champions within local institutions were non-existent.

Lessons from QSMAS demonstrate that a certain enabling environment is necessary for building adaptive capacity among local institutions and catalyzing widespread adoption of adaptive practices among farmers to withstand and respond to climate change and variability in Western Honduras. Because the benefits of many management practices that build resilience to climate shocks and stresses are not immediate, secure land tenure is critical for facilitating widespread adoption. Tenant farmers who shift plots every couple of years have limited incentive to invest in longer-term resilience-building measures. Meanwhile, a high level of social capital, in the form of active participation in community groups, is important as it enables collective action among farmers while helping to spread knowledge and information about adaptive practices to a wider group. In communities where farmers have limited participation in community groups and associations, social learning and the diffusion of information can be hindered, thereby limiting adoption. In addition, a diverse network of actors is critical for creating an 'innovation system,' which catalyzes the development and promotion of new practices and ideas as well as the integration of scientific knowledge with traditional knowledge. Finally, and perhaps most importantly, strong local institutions and local champions, especially within municipal governments, are critical for leadership and building trust between promoters of innovations and farmers while creating incentives for adoption.

Adaptive capacity of agricultural and environmental management institutions

A wide range of local and regional institutions play important roles in helping households and communities in Western Honduras anticipate, withstand and respond to climate change and variability. These institutions can be classified into three categories:

- **Public institutions**, including municipalities, *mancomunidades*, and line ministries (e.g., ICF, the Permanent Contingency Commission of Honduras [COPECO], etc.)
- **Civil society institutions**, including water boards (*juntas de agua*), local emergency committees (CODELES), community banks (*cajas rurales*), high schools (e.g., *Instituto Tecnologico Comunitario* [ICT]), universities, and NGOs
- **Private sector institutions**, including agricultural cooperatives, export groups, private extension providers, and input suppliers

KIIs and FGDs with representatives of regional and local institutions focusing on agriculture and environmental management in La Esperanza, Marcala, San Antonio del Norte, San Marcos de Ocotepeque, Tomalá, Belén Gualcho, and Jesús de Otoro revealed that institutions are aware of the threats of climate change and the need to adapt; however, they have limited human, financial, and technical capacity and resources to effectively implement measures to build resilience to climate change and variability. Table 14 provides a list of existing actions and interventions implemented by institutions to respond to climate-related impacts (as perceived by these local institutions). As the table demonstrates, local agricultural and environmental management institutions in Western Honduras are taking some important measures to respond to climate-related impacts; however, few are specifically tailored to address climate risk, and actions generally are not based on rigorous evidence and information on specific climate impacts. Some municipalities, particularly those that have strong presence of NGOs and donor-funded projects, are more advanced in terms of the actions they implement. For example, Belén Gualcho, which has received longstanding support from donor-funded projects and the NGO Aldea Global, is carrying out vulnerability and risk assessments, organizing CODELES, and developing early warning systems. Jesus de Otoro, which has strong local support from the Foundation for Participatory Farmer Research (FIPAH), is carrying out research on adaptive agricultural practices, developing an adaptation plan in the microwatershed of Santa Cruz, and installing meteorological stations.

TABLE 14. INSTITUTIONAL ACTIONS IMPLEMENTED BY LOCAL AGRICULTURAL AND ENVIRONMENTAL MANGEMENT INSTITUTIONS TO RESPOND TO CLIMATE-RELATED IMPACTS
(AS PERCEIVED BY LOCAL INSTITUTIONS)

Municipality	Actions implemented by local institutions to respond to climate-related impacts (as perceived by local institutions)
La Esperanza	• Community trainings in climate change • Forest management and water catchment protection • Technical assistance in water resources management
Marcala	• Reforestation of degraded areas and water catchments • Establishment of nurseries • Trainings in integrated water resources management • Community-based forest monitoring • Soil conservation practices and drip irrigation
San Antonio del Norte	• Youth education • Reforestation of water catchments • Community-based forest monitoring
San Marcos de Ocotopeque	• Diffusion of agricultural practices and technologies • Forest management and conservation measures • Agricultural finance • Training of farmers in adaptation • Watershed management plans • Drip irrigation
Tomalá	• Organization of *juntas de agua* • Establishment of tree nurseries • Delimitation of microwatersheds • Community organization • Inter-institutional coordination • Microfinance

Municipality	Actions implemented by local institutions to respond to climate-related impacts (as perceived by local institutions)
Belen Gualcho	• Organization of CODEM and CODEL • Vulnerability and risk management assessments • Early-warning systems • Reforestation and forest management • Construction of greenhouses • Water harvesting
Jesus de Otoro	• Participatory research in adaptive agricultural practices • Implementation of risk management plan • Adaptation plan in the *microcuenca* Santa Cruz • Agroforestry and on-farm diversification • Identification of vulnerable groups • Installation of meteorological stations

In addition to overall weak human, technical and financial capacity to respond to the threat of climate change and variability, our analysis of agricultural and environmental management institutions in Western Honduras found three significant institutional capacity gaps that hinder their ability to effectively build resilience to climate change impacts:

- **Lack of local research and extension programs tailored to agro-ecological zones of the Dry Corridor**. FGDs and KIIs revealed that there have been limited efforts in Western Honduras focused on local agricultural and environmental research and extension that is tailored to the diverse agro-ecological zones of the region. Most agricultural and environmental research takes place outside of the region – for example at the Honduran Foundation for Agricultural research (FHIA) and University of Zamorano research centers. Absent in the region are research and extension efforts focused on developing improved varieties of maize, beans, and coffee that are more heat/drought-tolerant and adapted to the conditions of the dry corridor. In addition, few research and extension efforts target natural resources management in agriculture, focusing on practices that will build resilience to climate-related shocks and stresses in the Dry Corridor. One exception is FIPAH's participatory research program on adaptive agricultural practices, which is a model that could be scaled up throughout the region.
- **Inadequate information available for adaptive decision-making at local levels**. Information and data are lacking for critical information needed to make decisions about climate change adaptation in Western Honduras, particularly information related to hydrology, soils, and land use. Our research found that where information exists, it is often concentrated at the national level and not shared or made available to decision-makers at the regional or municipal levels. There are also capacity gaps among decision-makers related to interpreting and analyzing this information in order to make climate-smart decisions.

- **Institutional focus has been on disaster response; insufficient emphasis on climate risk management and reduction.** While national and regional institutions are making efforts to mainstream disaster risk management and reduction into overall development processes, this has not yet translated into action at the local level in Western Honduras. CODEMS and CODELES, as well as activities implemented at the community-level, continue to focus primarily on response after disasters take place rather than on actions that build community-based resilience to climate risk.

2.5 ADAPTIVE CAPACITY AND THE PROTECTED AREA SYSTEM

As discussed in the Protected Areas analysis, Protected Areas play a critical role in building ecological resilience to climate change and variability in Western Honduras. They make up more than 13 percent of the region's total area, provide important water supplies for communities, regulate local climate and hydrological flows, and are an important tool for maintaining permanent land cover. However, significant threats are degrading the ecological functioning of Protected Areas in the region, particularly agricultural expansion for coffee production and subsistence agriculture. These threats are undermining the ability of Protected Areas to reduce the region's vulnerability to climate change.

Underlying these threats in Western Honduras are policy and governance failures. Only 7 of the 21 Protected Areas in the region have management plans. None of these existing management plans identify programs, strategies, actions, or activities related to climate change adaptation. ICF does not have the required institutional presence in the field nor do they have the financial resources to fulfill their constitutional commitment to manage or co-manage the region's Protected Areas. There is limited public awareness of the importance of Protected Areas and insufficient coordination among the actors and organizations that depend on the ecosystem benefits that these areas provide.

3.0 RECOMMENDATIONS AND ADAPTATION OPTIONS

The assessment team reviewed the major findings on exposure, sensitivity, and adaptive capacity. Based on these findings, the team developed a preliminary set of recommendations and adaptation options that fall along five adaptation pathways: knowledge generation, management, and learning; resilient water resources management; conservation of critical ecosystems; diversification; and risk management. These five pathways provide an overarching and holistic strategy that integrates sustainable land and water management into production systems and landscapes as a means for building resilience of ecosystems and livelihoods in the Western Honduras region to climate change and variability. We first provide an overview of each adaptation pathway and offer overall illustrative activities, followed by more detailed and specific adaptation options and recommendations for each sub-watershed that cut across the five adaptation pathways.

3.1 ADAPTATION PATHWAYS

Adaptation Pathway 1: Knowledge generation, management, and learning. The VA revealed significant gaps in the generation of knowledge needed to make adaptive decisions to respond to climate change in the Dry Corridor, the management and coordination of that knowledge, and decision-makers' subsequent application and learning. There is a strong need for local research and extension efforts tailored to the diverse agro-ecological conditions in Western Honduras. Research and extension activities should focus principally on climate-smart agriculture – with an emphasis on developing improved local varieties more resistant to temperature and precipitation extremes and co-identifying and effectively disseminating with farmers management practices that build resilience to climate-related shocks and stresses for maize, beans, coffee, and horticulture. Climate-smart agricultural research and extension activities should be complemented by research and extension efforts focusing on deepening an understanding of climate exposure and impacts through improved quality, availability, dissemination, and communication of climate information. Illustrative activities to support knowledge generation, management, and learning include:

- Establish a "Climate Change Knowledge Center" for the Dry Corridor region that serves as a "one-stop-shop" for all data and research on climate change in the Dry Corridor. The Climate Change Knowledge Center would provide information on, and develop awareness about, climate change impacts and adaptation responses in the Dry Corridor with the objective of influencing decision-making for cross-sectoral adaptation efforts in the region.
- Support participatory research and extension on climate-smart agriculture. Local research programs should be established in the Western Honduras region to improve heat-/drought- tolerant varieties for maize, beans, and coffee. Participatory research and extension efforts should be developed with farmers, extensionists and researchers to co-identify and scale-up the adoption and diffusion of on-farm soil and water management practices. Efforts should build upon existing models of participatory research in the region, such as FIPAH's program on adaptive practices and known successes or the Quesungual Slash-and-Mulch Agroforestry System.

- Create crop genebanks targeting maize, beans, coffee and potatoes. Crop genebanks should be created to maintain crop genetic diversity found in old and modern varieties, landraces, and wild relatives. Germplasm should be used to strengthen breeding programs and develop research projects in conjunction with local universities, the Honduran government, international partners, and NGOs.
- Support knowledge generation on forestry and agroforestry systems. Programs should promote the adoption of forestry and agroforestry systems—including fruit trees and timber products—as climate-resilient livelihood options.
- Improve climate information, compilation, analysis, access, dissemination, and communication.
- Research, develop, and scale-up climate-smart improved varieties, crop and natural resources management practices, and pest/disease management practices.
- Create germplasm banks for resistant varieties.
- Engage the private sector in programs to develop improved varieties and the use of information and communications technologies (ICT) to disseminate climate and weather information to local levels.
- Develop research programs on forestry and agroforestry, including fruit trees and timber products, and determine the climate resilience of these livelihood options.

Adaptation Pathway 2: Resilient water resources management. At its core, adaptation to climate change impacts in Western Honduras requires building the resilience of the region's water resources. To do this, decision-makers must have access to credible hydrological information to make management decisions in the face of an uncertain climate future. Efforts are needed to improve the evidence and information base on quantity and quality of water resources in Western Honduras as well as on-farm and watershed-level interventions that effectively build resilience to climate impacts on watersheds. Activities should target sub-watersheds that are considered most vulnerable from an eco-hydrological standpoint; the eco-hydrology analysis identified El Venado-Lempa, San Juan-Lempa, Higuito, and Mocal-Lempa as most vulnerable. Illustrative activities to build resilient water resources in Western Honduras follow:

- Improve the quantity, quality, access, and monitoring of hydrological information and its dissemination to local decision-makers Efforts are needed to establish and enhance water quantity and quality monitoring activities implemented by local water boards. Capacity building efforts of local water boards are needed to improve information and monitoring of flows, source protection, metering, and billing.
- Protect key water sources through watershed management activities and reforestation, particularly in upper recharge areas of sub-watersheds.
- Identify and scale-up soil and water management practices among farmers to improve the management of soil moisture ("green water"), reduce evapotranspiration, and decrease runoff and soil erosion.
- Explore options for payment for hydrological services schemes, building on the example of the *Junta de Agua* (JAPOE) in Jesus de Otoro.
- Support the adoption of drip irrigation and water harvesting where appropriate.

Adaptation Pathway 3: Conservation of critical ecosystems. Building the resilience of critical ecosystems in Western Honduras is essential for reducing vulnerability to climate change and variability, as these ecosystems are essential for providing and protecting key ecosystem services for communities in the region, particularly water supplies, and for regulating local climate and hydrological flows. Actions should focus on protecting areas currently forested while restoring areas that have been cleared, particularly on steep slopes. Considerable effort is needed to mainstream climate considerations into Protected Area management, as management institutions and plans currently do not take into account climate impacts. Illustrative activities follow:

- Protect remaining natural forests and restore them in upper watersheds, particularly on steep slopes that have been cleared for basic grains production or pasture, using native tree species.
- Integrate climate change adaptation and resilience considerations into existing Protected Area management plans.
- Carry out a communications and advocacy campaign to educate citizens on the importance of Protected Areas, linkages between climate change and ecosystems, conservation laws, and their rights.
- Improve the management of Protected Area buffer zones and identify alternative livelihood options for communities living in buffer zones.
- Improve enforcement of current environmental laws and regulations that protect habitats, forests, watersheds, soils, and species.
- Improve communication and collaboration between national agencies, co-management agencies, municipalities, and communities for better local monitoring and enforcement of laws and regulations.

Adaptation Pathway 4: Diversification. Households in Western Honduras heavily depend on agricultural activities that are inherently vulnerable to climate change and variability. As the climate in Western Honduras becomes more variable in the future, agriculture as it is currently practiced is becoming a less viable livelihood option for rural families. Diversification, both within and outside of agriculture, is essential to buffer climate impacts and spread household financial risk. Considerable efforts are needed to identify, develop, and strengthen diversified on-farm and off-farm livelihood options that are more resilient to climate-related shocks and stresses. Illustrative activities follow:

- Identify and strengthen on-farm options that are more resilient to climate impacts, such as production of cashews, mangoes, plums, timber, avocadoes, cocoa, sesames, and tamarind, and strengthen and/or develop markets for these products.
- Identify and strengthen climate-resilient off-farm livelihood options, such as eco- or cultural tourism associated with Protected Areas, handicrafts, and processing of agricultural and forestry products. The use of remittances and microcredit should be explored as opportunities to facilitate off-farm livelihoods diversification and the development of rural microenterprises.
- Establish new and support existing vocational education programs targeting youth to support on-farm and off-farm livelihood diversification in areas such as agriculture, forestry, water management, post-harvest processing, eco- and cultural tourism, microenterprise development, and entrepreneurship. These programs should build on existing successful models of vocational programs for youth, such as the Instituto Comunitario Tecnologico (ITC) in Candelaria and Tomala, Lempira.

Adaptation Pathway 5: Risk Management. Local institutions in Western Honduras have focused principally on disaster response without sufficient understanding and attention placed on climate risk management and reduction. Efforts are needed at the municipal and community level in Western

Honduras to build the capacity of local institutions, particularly CODEMS and CODELES, to reduce the risk of climate-related disasters. Illustrative activities follow:

- Strengthen the meteorological network for Western Honduras and improve the linkages between hydrometeorological information and early warning systems.
- Increase the adoption of climate risk assessment tools and information available to local institutions at the municipal and community levels to integrate into planning processes.
- Build the capacity of COPECO, CODEMS, and CODELES in disaster risk reduction and response, including contingency planning, community mobilization, and communication. Training and capacity building for CODELES are needed in community-based risk and vulnerability assessments and developing local contingency plans that take into account climate risks.
- Identify and improve at-risk infrastructure (roads, bridges, houses, grain storage, etc.). Climate change considerations should be taken into account in the development and site locations of new infrastructure. Efforts are needed to identify existing infrastructure in municipalities that are vulnerable to climate change impacts.
- Improve seed banks and grain storage at the municipal and community levels.

3.2 SPECIFIC RECOMMENDATIONS AND ADAPTATION OPTIONS BY SUB-WATERSHED

3.2.1 San Juan

Climate adaptation options to build resilience in the San Juan sub-watershed should focus on watershed protection especially in and around the Opalaca Biological Reserve. Coffee diversification with fruit and wood trees would also help to increase water retention capacity of the soil. Extension efforts to introduce climate-smart technologies and innovations to increase agricultural productivity of maize and bean production is needed, including improved drought-resistant corn and bean varieties, Integrated Pest Management, more access and efficient management of water resources both “green” (soil moisture) and “blue” water (surface water), and enhanced soil fertility management. Although no studies exist yet, field observations indicate that water harvesting might be an option to provide supplemental irrigation in short drought periods during the rainy season. As remittances play an important role for families and the local economy in the San Juan sub-watershed, opportunities to use them as part of financing mechanisms for long-term economic growth should be explored.

3.2.2 Gualcarque

Given the importance of Gualcarque as a water production catchment, priority climate adaptation options should focus on effectively protecting permanent land cover, especially in the Protected Areas of Puca, Opalaca, Montaña Verde, and Mixcure. This goal can be achieved by strengthening the capacity of co-managers and involving local governments and community organizations to protect the ecosystems services derived from these areas. Extension efforts are needed to increase agricultural productivity through climate-smart practices, including improved soil and water management, improved drought-resistant varieties, IPM, and supporting coffee processing to prevent water pollution. Due to increasing demand for fruit products, especially in the San Pedro Sula market, fruit production should be promoted to increase permanent land cover in the sub-watershed, especially on hillsides that are vulnerable to erosion. This way, future investment in downstream reservoirs (which is already planned for flood control, irrigation, and hydropower in the Ulua River) would be better protected.

3.2.3 Mejocote

Climate adaptation options to build resilience in the Mejocote sub-watershed should focus on increased local governance in Protected Areas and increasing productivity of both land and water resources. Soil and water management should be promoted to reduce the risk of erosion, sedimentation, and subsequent pollution of water supplies. Road construction on steep lands and vulnerable soils must be avoided to prevent landslides and increased pollution sources to this important sub-watershed.

3.2.4 Grande de Otoro

The eco-hydrological vulnerability analysis identified this sub-watershed to be less vulnerable to climate change due to its high percentage of permanent land cover and relatively high water production potential. However, due to the expansion of irrigated rice in the sub-watershed and associated increase in water demand, competition between water users in the valley and upper watershed is increasing. Climate adaptation options to build resilience in the sub-watershed should focus on increasing local water governance to establish reliable water accounting mechanisms; improved hydrological monitoring is needed to guide more efficient use of water. Extension efforts with rice producers in the valley are needed to increase water productivity of rice production.

3.2.5 Mocal Lempa

Maize and bean production systems in Mocal Lempa have low productivity due to lack of use of improved techniques (soil and water management, improved seeds, agrochemicals). There is limited diversification of livelihoods in the sub-watershed; however, coffee plantations are expanding in the upper catchment. Irrigation is currently limited in the sub-watershed; however, there are plans in the municipality of Tomala to promote the construction of small dams for hydropower generation (35 MB) and irrigation for agriculture along stream valleys. Potential climate adaptation measures should focus on increasing green water management through improved farming practices (soil and water management). Crop diversification should be promoted, especially fruit trees and agroforestry to increase permanent land cover. Land tenure was identified as a major constraint for wider adoption of natural resources management practices in the sub-watershed. It is common for smallholder farmers to cultivate maize and beans on communal lands, which hinders long-term land management. Options should be explored to address land tenure issues in the sub-watershed, as these are an obstacle to building resilience to climate change.

3.2.6 El Venado Lempa

Climate adaptation strategies should focus on increasing soil water retention through the promotion of improved agricultural practices. Due to the relatively high percentage of land under forest cover in the sub-watershed, community forest management could provide a potential source of income if properly planned. Small irrigation systems might be an option for supplemental irrigation. Water harvesting could also be an option on flat and rolling hills that are common along the road from La Esperanza to San Juan, Lempira. FGDs expressed the need for improved varieties for maize, beans, and potatoes.

3.2.7 Higuito

Priority climate adaptation options in Higuito should focus on increasing permanent land cover through protection of existing forests, promotion of agroforestry, and incorporation of fruit trees. Production systems must integrate climate-smart practices, including soil and water management, to increase green water retention. During FGDs, farmers also expressed the need for extension services to provide technical assistance on improved varieties, integrated pest management, efficient irrigation, proper agrochemical usage, and better financing mechanisms.

3.2.8 Palagua-Goascoran

Climate change and variability might affect crop and animal production, leading to potential food shortages. According to field observation during our visits, upper watershed areas have lost water retention capacity, runoff is frequent, and streamflow rises very quickly after a storm event. According to FGDs, a climate change adaptation strategy must target improved water access and management from the Goascoran River. There are important areas along the river flood plains that have the potential to be irrigated. Finally, for both agriculture and animal production there is a need for improved soil and water conservation.

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