HOW FORESTS ENHANCE RESILIENCE TO CLIMATE CHANGE

Case Studies from Burkina Faso, Honduras and Lao PDR

PROFOR
PROGRAM ON FORESTS

Disclaimer:

The findings, interpretations, and conclusions expressed in this paper do not necessarily reflect the views of the Executive Directors of the World Bank or the governments they represent or the donors of PROFOR and TFESSD. The World Bank does not guarantee the accuracy of the data included in this work. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of the World Bank Group concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

Suggested citation: Chandrasekharan Behr, Diji, Lisa Robins, and Aaron J.M. Russell. How Forests Enhance Resilience to Climate Change: What We Know and Case Studies from Burkina Faso, Honduras and Lao PDR. Washington DC: Program on Forests (PROFOR).

ISBN: 978-0-9910407-4-2

HOW FORESTS ENHANCE RESILIENCE TO CLIMATE CHANGE

Case Studies from Burkina Faso, Honduras and Lao PDR

TABLE OF CONTENTS

List of Tables

List of Figures

Acknowledgments

The synthesis report is one of five outputs associated with a larger project designed and led by Diji Chandrasekharan Behr (Senior Natural Resources Specialist, World Bank) on the role of forests in enhancing resilience to climate change (www.profor.info/node/2032). This synthesis report draws heavily on the technical synthesis report submitted by Lisa Robins and Aaron Russell to PROFOR.

This synthesis report brings together work that was commissioned as part of this project in three countries (Burkina Faso, Honduras, and Lao PDR) and a state of knowledge report. Several scientists were involved with the various technical reports that were the basis of the case studies and state of knowledge report. More specifically, Aaron J. M. Russell, Bruno Locatelli, and Emilia Pramova (CIFOR) prepared the technical report that formed the basis of the state of knowledge report. The climate and land use change modeling used in the country studies was conducted by Serge Rafanoharana, Bruno Locatelli, and Aaron J. M. Russell. Data collection and analysis in Burkina Faso involved Denis Gautier (CIRAD-CIFOR), Maam Suwadu Sakho-Jimbira (CIFOR), Cathérine A. K. Coulibaly Péhou (CIFOR Consultant), Jean-Paul Laude, Dr. Frank Richter, Marion Mundhenk, Martial Charpin, and Mamadou Lamine Bodincase. Framework development, data collection, and analysis for the Honduras case study involved Amanda Procter, Angela Díaz Briones, Raffaele Vignola, and Tim McDaniels, with contributions from Serge Rafanoharana, Bruno Locatelli, and Aaron J. M. Russell. The data collection and analysis in the technical case study on Lao PDR involved Aaron J. M. Russell, Joost Foppes, Sounthone Ketphanh, Somphachanh Vongphasouvanh, Serge Rafanoharana, Bruno Locatelli, Laykham Sihanat, Phayvone Phonephanom, Khonesavanh Louangsouvanh, Nellie Anyango Nakondiege, and Somcham Nanthavong. The work in Lao PDR was done in partnership with the Forestry Research Center within the National Agricultural and Forestry Research Institute and the Department of Forestry.

The work was under the management of Valerie Hickey (acting Practice Manager, GENDR, World Bank). Technical review of the synthesis report was provided by Kanta Kumari (Lead Environmental Specialist, World Bank). Technical review of the country case studies associated with the synthesis report was provided by: Loic Braune (Natural Resource Management Specialist, World Bank), Hocine Chalal (Lead Environmental Specialist, World Bank), Christian Peter (Lead Environmental Specialist, World Bank), and Sergei Zorya (Senior Economist, World Bank). Laura Ivers (Senior Communications Officer), Veronica Jarrin (Operations Analyst, World Bank), James T. Cantrell (Communications Analyst), and Linda Starke (editor) assisted with this activity.

Financial support for this work was provided by the Program on Forests (PROFOR) and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD). A multidonor partnership housed at the World Bank, PROFOR finances forest-related analysis and processes that support improving people's livelihoods through better management of forests and trees, enhancing forest law enforcement and governance, financing sustainable forest management, and coordinating forest policy across sectors.

Acronyms

CIFOR	Center for International Forestry Research
CO2	carbon dioxide
COP	Conference of the Parties
DDF	dryland diptercarp forest
EBA	ecosystem-based adaptation
ENSO	El Niño/La Niña-Southern Oscillation
ES	ecosystem services
FCFA	Communauté financière d'Afrique franc
FDI	foreign direct investment
GCM	global climate models
GHG	greenhouse gas
ha	hectare
ICF	Ministry of Forests and Conservation (Honduras)
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
LPG	liquefied petroleum gas
LPJ	Lund-Potsdam-Jena (dynamic global vegetation model)
LUC	land use change
MECV	Ministère de l'Environnement et du Cadre de Vie (Ministry of Environment and the Quality of Life)
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NGO	non-governmental organization
NPP	net primary productivity
NTFP	non-timber forest product
PDR	(Lao) People's Democratic Republic
PES	payment for environmental services
PROFOR	Program on Forests (World Bank)
PSFM	Sustainable Forest Management through Rural Development (Lao PDR)
REDD+	reducing emissions from deforestation and degradation and enhancing carbon stocks
SANAA	National Autonomous Water Works Services (Honduras)
TFESSD	Trust Fund for Environmentally and Socially Sustainable Development
UNFCCC	United Nations Framework Convention on Climate Change

All dollar amounts are U.S. dollars unless otherwise indicated.

1 EXECUTIVE SUMMARY

Many studies have examined the role of forests as stores of carbon, but relatively few studies have looked at the role of forests in adaptation to climate change. The low profile of forests in the adaptation discussion is surprising, given that the role of forests in generating ecosystem services is widely accepted and there is growing recognition of the potential of land management and control of land use changes to contribute to climate change mitigation.

For poor households in vulnerable areas, ecosystem-based approaches (EBAs) are often the sole or primary adaptation option available. For example, studies on the importance of including shade trees to protect agricultural crops from climate variability and climate extremes reveal how households use trees as a natural buffer against fluctuations in temperature, excessive solar radiation, reduced soil moisture, and other climatic variables. EBA approaches therefore can increase the adaptive capacity of natural or human-made systems to climate change, as well as bolster the effectiveness of more conventional investments and adaptation approaches.

But there are still important gaps in our knowledge of EBA approaches. For example, more work is needed on the costs of EBA approaches. Cost information would give decision makers a sense of the best EBA measures available in a given situation, and help them make an informed selection among adaptation strategies or in blending different strategies.

This synthesis report presents on overview of relevant work on the use of forests and trees in adaptation to climate change. It draws heavily on three new case studies—in Burkina Faso on forests and energy, in Honduras on forests and water, and in the Lao People's Democratic Republic (PDR) on forests and agriculture. The report describes how forests can enhance societal resilience to climate change. Conclusions and recommendations are drawn from these case studies and from a broader literature review.

Climate change and climate variability

Even with very ambitious mitigation action, the world is already locked into a path of warming close to 1.5°C above pre-industrial levels by midcentury. Based on current emission pathways, this increase in temperature could occur as early as 2040.

In Africa, the key risks posed by climate change include water stress and reduced crop productivity. The region's water resources are currently characterized by overexploitation, degradation, and rising anticipated demand for water, with drought stress worsening in the continent's drought-prone regions. Heat and drought stress are associated with declines in crop productivity. This is expected to have strong adverse effects on regional, national, and household livelihoods and food security. The impacts are expected to be compounded by increased pest and disease damage. In Asia, the key risks include increased risk of heat-related mortality and drought-related water and food shortages. In Central and South America, one key risk is extreme precipitation that can cause flooding and landslides in urban and rural areas.

Many regions of the world are already seeing evidence of aggravated climate variability, including increased frequency of droughts and storms and more erratic or intense rainfall patterns. For example, El Niño or El Niño/La Niña-Southern Oscillation (ENSO) events have been causing significant climate hazards in Central and South America; annual rainfall in the African Sahel declined by 25–30 percent between 1960 and 2000; and Southeast Asia has experienced a range of climate extremes in recent decades, including overall declines in rainfall, extreme variability in intra-annual rainfall patterns, increased frequency of heat waves, and increased frequency of tropical cyclones.

Two key concepts in the literature—resilience and vulnerability—are described in Box ES-1.

BOX ES-1. THE KEY CONCEPTS

THE CONCEPTS OF "RESILIENCE" AND "VULNERABILITY" ARE EMBEDDED WITHIN MANY DISCUSSIONS ON CLIMATE CHANGE ADAPTATION.

RESILIENCE, FROM A SOCIOECOLOGICAL SYSTEM PERSPECTIVE, IS CHARACTERIZED BY THE AMOUNT OF CHANGE THAT A SYSTEM CAN UNDERGO AND STILL RETAIN A DESIRED FUNCTION AND STRUCTURE. THE RESILIENCE CONCEPT IS VERY USEFUL FOR UNDERSTANDING THE TYPES OF MANAGEMENT THAT UNDERMINE ECOSYSTEM ADAPTATION. MAINTAINING AN ECOSYSTEM'S CAPACITY TO CHANGE AND REORGANIZE, AS WELL AS TO ABSORB SUDDEN SHOCKS, IS OF CRITICAL IMPORTANCE.

VULNERABILITY HAS BEEN DEFINED DIFFERENTLY BY PRACTITIONERS AND RESEARCHERS AND HAS FREQUENTLY BEEN RELATED TO CONCEPTS OF RISK, HAZARD, SENSITIVITY, EXPOSURE, ADAPTIVE CAPACITY, RESILIENCE, AND POTENTIAL IMPACTS. HERE WE USE THE DEFINITION OF VULNERABILITY PROPOSED BY THE IPCC (2014): "THE PROPENSITY OR PREDISPOSITION TO BE ADVERSELY AFFECTED. VULNERABILITY ENCOMPASSES A VARIETY OF CONCEPTS AND ELEMENTS INCLUDING SENSITIVITY OR SUSCEPTIBILITY TO HARM AND LACK OF CAPACITY TO COPE AND ADAPT."

THE IPCC APPROACH TO ANALYZING VULNERABILITY INTEGRATES ASSESSMENTS OF EXTERNAL FACTORS (EXPOSURE) AND INTERNAL FACTORS (SENSITIVITY AND ADAPTIVE CAPACITY), AND CONSIDERS BOTH SOCIOECONOMIC AND BIOPHYSICAL FACTORS. THE BASIC FRAMEWORK FOR CLIMATE CHANGE ADAPTATION INCLUDES: (A) *REDUCED EXPOSURE*, SUCH AS RELOCATING A COMMUNITY FROM A FLOOD-PRONE AREA OR IMPLEMENTING AN EMERGENCY ALERT SYSTEM; (B) *REDUCED SENSITIVITY*, SUCH AS PLANTING NEW CROPS RESISTANT TO DROUGHT OR CREATING CONSTRUCTION NORMS FOR BUILDING IN HAZARD-PRONE AREAS; AND (C) *INCREASED ADAPTIVE CAPACITY*, SUCH AS BY INCREASING EDUCATION OR DESIGNING INSURANCE SCHEMES.

Forests and Adaptation

Forests and adaptation can be linked in two ways.

- Forests can be used to strengthen societal adaptation to climate change. They provide critical ecosystem services, such as wood, non-timber forest products (NTFPs), and watershed hydrological regulation.
- Forest structures, species, and species distributions are being modified by climate change. Responding to this requires adaptation of forests themselves in order to prevent degradation of forest resources and to protect the ecosystem services that society relies on for adaptation.

The goods from forests (such as timber, poles, non-timber forest products, and fuel) help households to diversify their livelihood portfolio. Income from such sources accounts for about 28 percent of total household income for forest-dependent households, and is even more important in periods of stress. Other recent studies have indicated that rural populations in developing countries—particularly women-led households in many poor rural areas— receive on average roughly 25 percent of their income from harvesting NTFPs (including shoots, roots, mushrooms, wildlife, and insects), and that many rural communities rely on timber and charcoal resources as key sources of income (through either direct sale or salaried labor) and as particularly valuable means for recuperating the loss of productive capital following livelihood shocks.

During the drought years of 2005–06 in Tanzania, for example, some 85 percent of interviewed households indicated their reliance on forest provisioning services (particularly wild fruits and firewood), which was estimated to provide 42 percent of their total income during these years. In Honduras, poor rural households sold forest products to self-insure after being unable to recoup landholdings that were lost due to Hurricane Mitch.

Agroforestry landscapes. A substantial body of research has produced evidence on the benefits of agroforestry. Long-term research has shown that fertilizer tree systems (using nitrogen-fixing trees such as ***Faidherbia albida***), when intercropped with maize, contribute to increased drought resilience of maize due to the combined effects of improved soil nutrient levels and increased water infiltration into the soil. Other studies have documented the contributions of shade trees to protecting coffee agriculture from climate variability and climate extremes. In some contexts, agroforestry approaches may be more successful than agricultural intensification in addressing some of the threats to agricultural systems posed by climate change.

Riverine and floodplain forests. Riverine and floodplain forests delay the passage of flood waters by causing water to meander through circuitous side branches, where physical resistance from vegetation and meandering riverbanks slows the movement of water. This gives downstream waters more time to subside. The increased risk of flooding in areas downstream from agricultural or non-forested floodplains is widely recognized as being higher than flooding downstream from forested floodplains.

Coastal mangroves. As in the case of floodplain forests, mangroves regulate primarily by creating a physical barrier to wave action, stabilizing the seafloor, and altering the slope of the sea flood.

In 1999, the state of Orissa in India was battered by a super-cyclone that killed almost 10,000 people and caused a massive loss of livestock (440,000 deaths) and property (almost 2 million damaged houses and over 1.8 million hectares of damaged crops). In the aftermath of the storm, a study established that mangrove forests could have significantly reduced the number of human casualties from the super-cyclone, as well as damages to homes near the coast.

In the context of predicted sea level rise, mangrove conservation and restoration may in many cases need to be paired with other adaptive strategies such as relocation of human settlements to higher ground. Overall, mangrove conservation provides numerous contributions to coastal livelihoods, including NTFPs for food security, fish habitats, regulation of salinization, and protection of biodiversity.

The Case Studies

The analytical framework for this study links vulnerability assessment and adaptation by bringing together multiple dimensions—a climate change model, the link between land use and climate change (a proxy for sensitivity), the economic or financial dimensions of using EBA, and the policy and institutional context required to implement EBA. Three country case studies were selected for this activity—Burkina Faso, Honduras, and Lao PDR.

Burkina Faso. Burkina Faso is a landlocked country in the middle of the West African Sahel region. It has arid and semiarid ecosystems. Roughly 80 percent of employment is linked to subsistence farming. The country's soils tend to be poor in nutrients, have low water-holding capacity, and are largely degraded. When rainfall declines, dust storms occur or the temperature spikes, and food supplies and yields are immediately affected. These fragile conditions have kept Burkina Faso at the bottom of the U.N.'s Human Development Index, ranking 162 out of 169 countries, with 46 percent of the population below the poverty line. Burkina Faso is prone to chronic drought, flash floods, wind storms, and disease outbreaks. The consequences of climate change are expected to be fairly severe over the next fifty years. Measures to improve water retention and cultivation resilience to climate variation have started, but they remain local and small in scale.

The case study assessed the contribution of "forests"—savannas, woodlands, and fallows—to the household energy sector's adaptation to climate change. It focused on wood energy to clarify how forest ecosystems can contribute significantly to the country's energy needs while actively contributing to a reduction in the vulnerability of the wood energy value chain. The recommendations aim to help Burkina Faso's energy system withstand shocks.

The case included a cost analysis of the implementation of two strategies—a modernization strategy of the wood energy value chain and a liquefied petroleum gas (LPG) strategy—under three scenarios using a simulation model for the period 2013–30. The three scenarios were base (business as usual), optimistic, and pessimistic. The base scenario assumes no impact of climate change on forest productivity, population growth of 3.4 percent per year in urban areas and 3.1 percent per year in rural areas, and regression of forest land area by 0.54 percent per year. The main difference between the optimistic and base scenario is a positive impact of climate change on forest productivity due to increased rainfall and a fertilizer effect of CO_2, resulting in a 15 percent increase by 2050 compared with 2013. The pessimistic scenario differs from the base scenario in that it assumes a negative impact of climate change on forest productivity due to high temperatures and high rainfall variability, leading to a 25 percent decrease in productivity by 2050 compared with 2013.

The analysis examines two types of development strategies: (1) a strategy for the modernization of the wood energy subsector, based mainly on the sustainable management of forest ecosystems and optimization procedures to the other links in the chain; and (2) a strategy that substitutes away from wood energy; in this study we used a primarily LPG strategy.

First, a strategy to modernize the wood energy value chain, which (a) is based primarily on the sustainable management of forest ecosystems and optimization of the other links in the value chain; (b) promotes increased energy diversification with the promotion of butane gas as a supplementary measure.; and (c) aims to achieve coverage for 90 percent of the energy needs of rural households from wood energy and 60 percent of urban households' needs.

To implement the first strategy, an action plan for the period 2014–18 would put under management a total area of approximately 805,000 hectares of forest; create 38,000 hectares of plantations and protect 260,000 hectares; distribute improved cookstoves on a large scale (390,000 stoves); and promote the use of butane gas to 160,000 households. Over the entire period from 2013–30, the forest area put under management varies between 2.1 million and 4.2 million ha, meeting approximately one-third of the wood energy strategy. The plantation area established is between 185,000 and 270,000 ha, depending on the scenario. The total cost in 2030 for the implementation of the modernization strategy of the wood energy value chain varies between 232.2 billion FCFA ($479.35 million) in the optimistic scenario and 306.3 billion FCFA ($632.32 million) in the pessimistic scenario. In addition to average annual costs, investments range between 13.7 billion and 18 billion FCFA (between $28.28 million and $37.16 million).

The LPG strategy simulation is based on approximately 2.2 million households being supplied by butane gas and the distribution of 950,000 improved cookstoves. The total costs are significantly lower than those of the modernization strategy and range from around 170 billion to 220 billion FCFA ($350.94 million to $454.16 million). The total annual costs of the LPG strategy are lower than the optimistic scenario for the wood energy strategy.

Implementing the modernization of the wood energy value chain will require numerous institutional measures, including (a) improving the sustainable production of wood energy by promoting participatory management of natural forests and increasing the area under plantations and agroforestry; (b) improving exploitation and processing of wood energy by building the capacity of local actors, increasing efficiency of resource use, and testing and disseminating innovative methods to use agricultural residues; (c) improving the transportation and marketing of wood energy; (d) testing models of improved household cookstoves and disseminating them in urban and rural areas; and (e) supporting the forest administration in the implementation of differential taxation of wood, adapting the regulatory and fiscal framework to develop a rural wood energy market and urban wood energy market, and decentralizing control by integrating local authorities and stakeholders into the system.

The use of wood energy can encourage landowners and farmers to better manage woodlands and invest in plantations. Wood energy production is perfect for community management of forests and woodlands and is in line with the current trend of deregulation and privatization of the energy and forestry sectors. In addition, the sustainable production of domestic fuels can lead to rural development consistent with coherent town and country planning. Forest resources are available locally and have a high potential for decentralized production and processing. The use of woody fuels promotes transport over relatively short distances with low environmental risks. Unlike other energy sources requiring more sophisticated technologies, woody fuels create jobs and income at the local level, especially for the poorest and most disadvantaged groups.

Honduras. In Honduras, the case study focused on the potential for using forest ecosystem-based approaches to adapt to the potential impact of climate change on the Guacerique watershed. Considered highly vulnerable to climate change, the Guacerique watershed (in the Choluteca river basin) is one of the most deforested in the country. The Guacerique's catchment services 25 percent of the water supply connections in Tegucigalpa, a city that is home to approximately 13 percent of the total population in Honduras (about 1.05 million people). Water managers are currently seeking to combine ecosystem- and infrastructure-based solutions to the water supply challenges they face.

The case study seeks to integrate climate change and ecosystem services (ES) modeling at the watershed scale with an economic analysis of the impacts of watershed management policies on water quality and quantity under high and low climate change scenarios.

Model results show that water runoff is predicted to decrease in almost all scenarios, with relative changes ranging from minus 31 percent to 0 by 2080. Similar results were found in the regional study that used 136 scenarios and another vegetation model. Even though precipitation decrease is not predicted in all cases, the certainty of temperature increases results in runoff decreases in all scenarios. This has major implications for the users of surface water in the study site.

The projected change in rainfall-induced erosion ranges from minus 28.8 percent to plus 5.3 percent by 2080. Most scenarios show a decrease in erosion due to decreasing rainfall, although our climate change scenarios consider only changes in mean precipitation, not in extreme events. Using land use and climate change scenarios specifically for the Guacerique watershed, we found that the potential benefits of decreased rainfall-induced erosion in 2080 (minus 28.8 percent) may easily be lost by inappropriate land use, resulting in very significant increases in erosion (plus 155.1 percent).

The national water utility (SANAA) and the Honduran Ministry of Forests and Conservation (ICF) have developed a watershed management plan for the Guacerique watershed with the overall objective of ensuring long-term water availability and lowering sediment loads in the Guacerique River in order to maximize the watershed's utility as a source of drinking water for Tegucigalpa. Among other things, the plan would reforest 1,236 ha around springs and creeks; create 100 ha of fuelwood plantations; implement agroforestry systems on 161 ha of steeply sloping agricultural land; and implement soil conservation measures on 2,000 ha of agricultural fields.

Community engagement constitutes SANAA's principal approach to implementation, as the utility recognizes that success depends on the communities' acceptance and support of the plan and its activities.

The authors of the study sought feedback from stakeholders on alternative governance approaches for successful EBA in the Guacerique watershed. Stakeholders identified a set of basic requirements for improving water and forest resource governance that would help reduce sensitivity to climate change and improve adaptive capacity. The actions are grouped into five categories: resource generation, government mandates, planning and learning, interinstitutional coordination, and implementation.

Actions to facilitate interinstitutional coordination respond to stakeholders' recognition that it is important to carry out activities at multiple scales—from the river basin down through the watershed, municipality, and community. Research shows that controlling land use change is the most important factor in achieving watershed management goals, and that building effective relationships with municipal governments and encouraging municipal exercise of land use planning mandates are essential. Furthermore, it is important to generate consensus among stakeholders on the objectives of any particular plan, policy, program, or initiative so that they agree on the problem and become empowered to act in ways that contribute to achieving collectively set goals.

With regard to implementation, stakeholders feel that providing communities with training and financial resources is an effective way to increase community participation in watershed management efforts. In this particular case, stakeholders see agricultural extension as key to improving land use and forest conservation, with important spinoffs for household well-being, including improved incomes and local and regional food security.

The overall annual economic benefit of the watershed management plan to the national water utility for the years 2030–35 is about $3.7 million under the low climate change scenario and about $9.2 million under the high climate change scenario. Assuming a moderate economic growth rate in the future, the net economic benefit of the watershed management plan is approximately $28.6 million under the low climate change scenario and $76.1 million under the high climate change scenario.

Lao PDR. Lao PDR has approximately 9.5 million hectares of forest cover, which constitutes 40 percent of the total land area. In 2012, an estimated 5 million ha were leased or conceded to domestic and foreign investors. The bulk of these areas were for mining concessions (primarily exploratory), followed by agricultural investments.

The southern provinces of Lao PDR have large areas available for leasing and concession. Some of the provinces in that region are home to the unique ecosystem of dry dipterocarp forests (DDF), which are important savanna-like forests. DDF represent 13 percent of the total forest estate, as well as a unique vegetative ecotype spanning parts of Southeast Asia, including endangered flora and fauna. These systems are increasingly targeted for conversion to commercial plantations. DDF systems, however, provide local stakeholders with a range of environmental services—most important, they provide fodder for livestock and other NTFPs for consumption and sale, both of which reduce households' sensitivity to climate change and strengthen their adaptive capacity. DDF also support rice production by regulating hydrological flows and limiting erosion.

The case study covers three villages in Savannakhet Province: (1) a PSFM village (Sustainable Forest Management through Rural Development), where no concessions occurred and where communal forestland covers 3.74 ha per person; (2) a eucalyptus village, where 45 percent of village forestland was converted to eucalyptus plantations and the remaining communal forest covers 0.73 ha per person; and (3) a sugarcane village, where 75 percent of village forestland was converted to sugarcane plantations and where there is no remaining communal forest.

The study sought to explore how forests, through the provision of environmental services, contribute to the adaptation of smallholder agriculture households in the DDF region. The methodology combines secondary data collection with national, provincial, and district stakeholder consultations; with village stakeholder participatory rural appraisals; and with an illustrative survey sampling of households about household demographics, sources of income, expenditures, and food self-sufficiency. It compares households with access to forests with households in areas with conversion of forests to large-scale eucalyptus and sugarcane concessions.

Across all three communities, forest resources constitute an average of 35 percent of annual total income. Communities with less forest relied to a greater extent on income from wage labor (8 percent in the PSFM village versus 29-33 percent the villages with concessions) and on remittances from migration (1 percent in the PSFM village versus 5–13 percent in the villages with concessions), and they had reduced livestock holdings. Due to limited demand for labor in sugarcane and eucalyptus concessions, the majority of labor income comes from outside the village.

In the PSFM village, forest resources were the primary source of cash income across wealth categories, through NTFPs (55 percent) and livestock sales (26 percent). The most important NTFPs were mushrooms (10 percent), frogs and snails (16 percent), insects (10 percent), and bamboo and rattan (7 percent). DDF provisioning services were valued at $54 per ha per year. Non-cash income in this village represented 68 percent of total income. In the other communities, non-cash income represented 35–41 percent of total income.

The value of livestock owned by households was equivalent to 3.6 years of average annual household cash income in the PSFM village, compared with 1.2 years in the eucalyptus village and 1.0 years in the sugarcane village. This illustrates the key role of livestock as a source of savings and/or a safety net mechanism during times of crisis.

Villagers estimated that their large livestock depend on natural stands of ***Arundinaria*** grass in DDFs for 80 percent of their grazing requirement. Fodder from forests therefore represents a significant source of resilience to shocks—a resource that is lost when DDF is converted to concessions. Elevated livestock sales in the eucalyptus village may reflect the loss of forest grazing land.

Findings from the Lao PDR case study demonstrate that ecosystem services provide an immediate and measurable source of annual returns to households through sale and/or replacement values for livestock, NTFPs, firewood, construction materials, and domestic water supplies. The value of the current estimated annual income in the PSFM village from these provisioning services is $20.66 per ha. In addition, after adding a conservative estimation of the contributions of

DDF to the regulation of the water supplies and erosion control for agricultural production, the total value of known, quantifiable ecosystem services is estimated at $46.97 per ha.

DDF land is increasingly targeted for conversion to commercial plantations, where large tracts of land are being allocated to foreign companies. This forms part of the Lao PDR government's attempt to leverage its land resources to attract foreign investment. Unfortunately it would appear that the concessions being granted provide very limited benefits for rural stakeholders, while undermining their livelihoods and resilience to shocks. National policy makers need to put in place mechanisms that better balance the needs of local livelihoods with national development priorities.

Conclusions

Forests generate provisioning, regulatory, and supporting services that can enhance the resilience of social and economic systems in other sectors. Existing evidence and the case studies described in this report reveal that forests offer economic assets that can help reduce sensitivity to climate change in other sectors and strengthen adaptive capacity through the supply of wood and non-wood products.

The cases find that land use change resulting from the allocation of concessions, illegal resource use, and unsustainable resource management interact with the consequences of climate change and often reduce the potential positive impacts or compound predicted negative impacts. Evidence from climate change and land use modeling on three key parameters—net primary productivity, runoff, and fire fraction—in the three country case studies shows how land use change can reduce possible gains in NPP, as was the case in Lao PDR and for most of the scenarios considered in Burkina Faso.

Forests can contribute most effectively to resilience when blended with other infrastructure measures. Adding forests as a form of ecosystem-based adaptation to infrastructure measures could generate medium- and long-term ecosystem benefits in addition to strengthening adaptation measures.

The use of forests to reduce vulnerability to climate change is likely to be optimized when done in combination with other adaptation measures. For example, the use of mangrove forests as coastal defense against severe weather events is often most effective when combined with dikes and breakwaters. Growing acceptance of this approach has resulted in what is known as "hybrid engineering," which combines engineering techniques with natural processes and resources.

Successful implementation of EBA has many institutional dimensions, including the following: Government agencies and authorities need to work more closely with communities in building a shared vision for landscapes and livelihoods.

Better coordination among authorities is essential to effectively implement EBA, including clarification of roles and responsibilities and improvements in reporting mechanisms.

To support the use of forests to enhance resilience to climate change in the three countries profiled in the case studies, it is necessary to support farmers' adoption of sustainable agriculture and forest management practices.

Successful EBA implementation requires a financial commitment by government and partner institutions.

Monitoring systems are vital to inform the development and adjustment of EBA responses. To enable the use of forests as an EBA approach, it will be imperative to refine, strengthen, and enforce plans and regulations based on climate change and variability projections, particularly with regard to forest conversion.

2 INTRODUCTION

Extreme and chronic manifestations of climate variability underscore the urgency of building resilience to climate change, reducing risks, and mitigating greenhouse gas (GHG) emissions. The impact of climate change is disproportionately harmful to poor and low-income households. In developing countries, these households are often most reliant on sectors that are vulnerable to changes in climate (agriculture, forestry, fisheries) and have limited capacity to adapt. Similarly, climate change negatively affects economic growth for vulnerable economies. Climate change compounds the challenge of achieving livelihood security and food security.

Estimates from 2010 of the cost of adapting to an approximately 2oC warmer world by midcentury are in the range of $70 billion to $100 billion a year (World Bank 2010). While many countries acknowledge the importance of adaptation and mitigation and have developed strategies on them, limited national budgets often result in priority being given to measures that reduce the vulnerability of specific areas—such as coastal areas, areas that are densely populated, and areas where there is "valuable" infrastructure such as energy infrastructure—leaving parts of the population vulnerable to the vagaries of climate change. The financial constraints and limited use of measures that reduce exposure of all parts of society accentuate the need to identify approaches that are cost-effective and can reduce existing spatial or socioeconomic bias in the implementation of adaptation and mitigation strategies. One such alternative approach is ecosystem-based adaptation (EBA). While mounting concerns regarding the impact of climate change in several countries have led to greater interest in infrastructure investments to reduce the impact of rising water levels, landslides, water shortages, and fires, the close interplay between land use change (LUC) and climate change[1] has informed several policy efforts. There is increased recognition of the potential of land management and control of land use changes to contribute to climate change mitigation. In 2009 the World Bank published a study that made a compelling case for including ecosystem-based approaches to mitigation and adaptation in national strategies (World Bank 2009). EBAs help address climate change, augment infrastructure-based adaptation strategies while increasing the mitigation of GHG emissions, and reduce vulnerability to climate variability. Existing evidence pointed to the need for integrated solutions that ensured that efforts to build resilience were not undermined by land use change. In 2011, the term "adaptation-based mitigation" was widely used in discussions on climate change.

Structural and physical options to reduce potentially irreversible consequences of climate change (because of associated loss of life and property) include approaches based on engineering and a built environment, technological approaches, EBA, and provision of services. Engineering and technological

1. Land use change, like climate variability and climate change, is an important environmental challenge. LUC and climate change are linked, as land use and land cover change contribute to climate change by affecting ecosystems' biogeochemical and biophysical processes (Houghton et al. 2012 and Pitman et al. 2009, as cited in Arneth et al. 2014). Climate change, in turn, shapes land use by affecting food supply and pollution impacts on ecosystems (Gornall et al. 2010, Easterling et al. 2007, and Ashmore 2005, as cited in Arneth et al. 2014).

investments range from irrigation technology and small-scale equipment to flood walls and dikes. For poor households residing in vulnerable areas with limited access to weather insurance or infrastructure-based investments, these possible options seldom generate much-needed protection or enhancement of their resilience. For these households, EBA is often the sole or primary adaptation option available. Studies on the importance of including shade trees to protect agricultural crops from climate variability and climate extremes reveal how households use trees as a natural buffer against fluctuations in temperature, excessive solar radiation, reduced soil moisture, and other climatic variables to which some crops are extremely sensitive. EBA approaches therefore can increase the adaptive capacity of natural or human-made systems to climate change and bolster the effectiveness of more conventional investments and approaches in adaptation to climate change.

Ecosystem-based adaptation uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to climate change (UNEP, 2013). The United Nations Framework Convention on Climate Change (UNFCCC) Cancun Adaptation Framework identified EBA as building ecological resilience and noted the priority of vulnerable ecosystems for adaptation as important for success in this approach. Paired with infrastructure investments, EBA can, in addition to enhancing resilience, generate multiple social, economic, and cultural benefits for local stakeholders.

There are numerous anecdotal case studies and some scientific studies on the effectiveness of EBA systems, including a few quantitative ones (such as cost-benefit studies). Very few, however, have any kind of control situation or counterfactual. A review by the Cambridge Conservation Initiative found that while many studies pointed to the EBA approach as being effective, there were several knowledge gaps (Cambridge Conservation Initiative 2012). One area needing more work is the costs of EBA approaches. Cost information would help give decision makers a sense of the type of EBA measures that would be optimal and applicable in their situation and would allow them to make an informed selection among adaptation strategies or to blend different strategies.

With the opportunities presented by EBA and the potential of some of these approaches to also have mitigation benefits, this Program on Forests (PROFOR) study examines the use of forests to enhance resilience to climate change. The role of forests as stores of carbon—therefore reducing GHG emissions—has been captured in the efforts associated with reducing emissions from deforestation and degradation and enhancing carbon stocks (REDD+). Forests have featured less prominently in the arena of adaptation. Only a few National Adaptation Programmes for Action (NAPAs) mention the need to adapt forest systems to changing climates. The low profile of forests in the adaptation discussion is surprising, given that the role of forests in generating ecosystem services is widely accepted.

Concrete efforts are under way to document how forests may assist in adaptation to climate change. Alongside these efforts are initiatives to conduct detailed assessments of the impact of future climate change scenarios on natural resources. Forests and adaptation can be linked in two ways.

- Forests can be used to strengthen societal adaptation to climate change, as they provide critical ecosystem services, such as wood, non-timber forest products (NTFPs), and watershed hydrological regulation, the values of which are usually underestimated by society ("forests for adaptation").
- Forest structures, species, and species distributions are being modified by climate change. Responding to this requires adaptation of forests themselves in order to prevent degradation of forest resources and to protect the ecosystem services that society relies on for adaptation ("adaptation for forests").

The scope of this PROFOR study was to improve understanding of how forests could reduce the vulnerability of other sectors to climate change. The study first developed a conceptual framework for analyzing the potential to use forests to adapt to climate change (including examining the economic rationale of EBA) and then tested the application of the framework in the use of forests to enhance resilience to climate change in three different sectors. The study included three case studies that explored how forests, through the provision of ecosystem services, contribute to adaptation to climate change in agriculture, energy, and water. The analytical framework examined both land use change and climate change. In addition, the study collected available data to capture the financial value of using forest- or tree-based EBA measures. The findings point to the potential value of using EBA to augment infrastructure- or technology-based adaptation measures and to build the resilience of the rural poor.

At its inception, this study aimed to augment efforts to promote ecosystem-based adaptation with evidence of the financial value of EBA approaches, specifically those involving forests. Another goal was to make explicit the linkage between forests and the adaptation strategies in other sectors; to highlight the type of forest/tree management and use regime that would generate benefits; and to examine, where possible, the type of institutional arrangement, incentives, or initiatives that would encourage the use of forests for adaptation in other sectors. The original approach was to also compile data on the use of forests for adaptation and other approaches to climate change adaptation and compare the two situations. Due to difficulties in collecting data on the latter, information on alternative adaptation approaches is limited.

This Synthesis Report presents on overview of relevant work on the use of forests and trees in adaptation to climate change. Drawing heavily on three case studies—on Burkina Faso (forests and energy), Honduras (forests and water), and the Lao People's Democratic Republic (PDR) (forests and agriculture)—the report presents how forests can enhance societal resilience to climate change. It also briefly presents the approaches adopted to elicit the necessary information and provides observations on their effectiveness. Conclusions and recommendations are drawn from these case studies and from a broader literature review.

2 CLIMATE CHANGE

2.1 What does the future hold?

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that globally averaged combined land and ocean surface temperature data show a warming of 0.85 degrees Celsius (°C) from 1880 to 2012 (IPCC 2013). Although seemingly a modest increase, this change in mean temperature is already associated with the melting of ice from the Greenland and Antarctic ice sheets, increased frequency of heat waves, and other negative impacts (World Bank 2012). Higher temperatures also have a detrimental impact on economic growth in poor countries. Recent models predict that without further commitment and action to reduce greenhouse gas emissions, the world is likely to warm by 4°C above the preindustrial climate (World Bank 2012). With current mitigation commitments and pledges fully implemented, there remains a 20 percent chance of exceeding a warming by 4°C by 2100 (World Bank 2012).

The World Bank (2012) outlines "what the world would be like if it warmed by 4°Celsius, which is what scientists are nearly unanimously predicting by the end of the century, without serious policy changes" (p. v). It argues that while there are a range of high and low climate change scenarios, the world is likely to face high climate change outcomes, given the poor commitment of nations globally to reduce GHG emissions, and that these impacts are unpredictable given our current understanding. The report warns that impacts are likely to include sudden and non-linear shifts in conditions rather than gradual ones that can be planned for. While today's institutions and strategies might cope with a change of 2°C, they are unlikely to cope with a 4°C world.

The World Bank (2012) report also states that even with very ambitious mitigation action, the world is already locked into a path of warming close to 1.5°C above pre-industrial levels by midcentury. Accordingly, based on current emission pathways, this increase in temperature could occur as early as 2040. Where management of natural forest stands or slow-growing tree species are part of the proposed EBA, measures will need to be taken to adapt forest management in order to deliver their adaptation benefits.

The recent IPCC report shows that the key risks (with high confidence) for the Africa region include water stress and reduced crop productivity (IPCC 2014). The impact of water stems from overexploitation and degradation at present and anticipated demand for water, with drought stress exacerbated in drought-prone regions of Africa. Decline in crop productivity is associated with heat and drought stress. This is expected to have strong adverse effects on regional, national, and household livelihood and food security. The impacts are expected to be compounded by increased pest and disease damage on the systems. In Asia, the key risks identified with high confidence include increased risk of heat-related mortality and increased risk of drought-related water and food shortage. In Central and South America, a key risk is extreme precipitation that can cause flooding and landslides in urban and rural areas.

IPCC reports include an analysis of vulnerability of different ecosystems to climate change, including terrestrial and freshwater systems (IPCC 2014). The analysis points to climate change as a powerful stress on terrestrial systems in the second half of the twenty-first century. In the next three decades, direct human impact from land use and land use change will affect terrestrial ecosystems globally. When these are substantially altered, through either climate change or other mechanisms, local, regional, and global climates are also affected. Climate change is also expected to reduce the vigor, variability, and population of spatially restricted species.

Carbon stored in vulnerable terrestrial biospheres is expected to be released from the direct or indirect effects of climate change, deforestation, and degradation. Increased ecosystem disturbances from wind storms, fires, pest outbreaks, and droughts, as they exceed the natural variability in the system, could alter natural structures. Increases in tree deaths are already seen in many places, some of which is directly associated with higher temperatures and droughts. The IPCC report states that management actions can reduce, but not eliminate, the risk of impact to terrestrial and freshwater ecosystems due to climate change (IPCC 2014). This can help increase the capacity of ecosystems and species to adapt. Measures to mitigate and adapt to climate change need to be carefully designed to prevent any unintended consequences to natural systems.

2.2 Climate change vs. climate variability

While there is some uncertainty regarding the specific extent to which the climate will change in different parts of the globe in the coming decades, many regions of the world are already having to address trends of aggravated climate variability (such as increased frequency of droughts and storms and more erratic or intense rainfall patterns). Even though there are many uncertainties related to climate change, aggravated climate variability is occurring now and is projected to increase in the future—with increasingly severe impacts on both ecosystems and societies.

A typical example of aggravated climate variability that is thought to be a result of climate change is the increased frequency of El Niño or El Niño/La Niña-Southern Oscillation (ENSO) events during the past few decades (Qiong et al. 2008). ENSO events have been causing significant climate hazards in Central and South America, where they have become more intense and frequent since the mid-1970s (Poveda, Waylen, and Pulwarty 2006). However, through the interconnectedness of global weather systems, ENSO events can result in extreme weather (such as floods and droughts) in many regions of the world.

Similarly, annual rainfall in the African Sahel declined by 25–30 percent between 1960 and 2000. Global climate change scenarios predict that this trend will continue through 2050 (Mortimore 2010). Southeast Asia has also experienced a range of climate extremes during recent decades, including overall declines in rainfall, extreme variability in intra-annual rainfall patterns, increased frequency of heat waves, and increased frequency of tropical cyclones (ADB 2009). While attention is rightly focused on addressing climate change, it is important to recall that the Millennium Ecosystem Assessment and several scientific studies have concluded that human activity is having a significant and escalating impact on the world's ecosystems and their ability to provide services, aggravating the adverse impacts of other drivers of change such as climate change (MA 2005). In the short to medium term, changes in climate may not always be the most significant driver of landscape-level change. In many cases, the negative impacts of climate change will be compounded by societal decisions regarding forest governance and land-use/coastal zone planning. Therefore, reducing vulnerability to climate change can require engagements that are related to management and the policy framework, in addition to investments in both natural and human-made structures.

3 VULNERABILITY AND CLIMATE CHANGE ADAPTATION

3.1 Defining the concepts

The concepts of "resilience" and "vulnerability" are embedded within many discussions on climate change adaptation.

Resilience, from a socioecological system perspective, is characterized by the amount of change that a system can undergo and still retain a desired function and structure, the degree to which the system is capable of self-organization, and the system's ability to build and increase its capacity for learning and adaptation (Gunderson and Holling 2002; Walker et al. 2006).[2]

Vulnerability is a more operational concept. Due to its application in an array of settings (such as disaster relief, livelihood development, health management, climate change, psychology, and risk management), vulnerability has been defined differently by practitioners and researchers and has frequently been related to concepts of risk, hazard, sensitivity, exposure, adaptive capacity, resilience, and potential impacts (Brooks 2003; Eakin and Luers 2006). Here we use the definition of vulnerability proposed by the IPCC (2014): "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."

For purposes of this study, this is interpreted as the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (McCarthy et al. 2001, p. 995).

"Adaptive management" is founded upon a resilience-based understanding of ecological function and change. It is based on the notion that change is episodic rather than gradual and continuous. At a certain scale, the spatial organization of a system is patchy and there are non-linear processes among different spatial scales. The adaptive management approach also values variability and finds that destabilizing forces are needed to maintain structure and diversity, while stabilizing forces help maintain productivity (Holling 1973, 1978; Holling and Meffe 1996; Holling and Sanderson 1996).

2. See also Resilience Alliance 2001: www.resalliance.org.

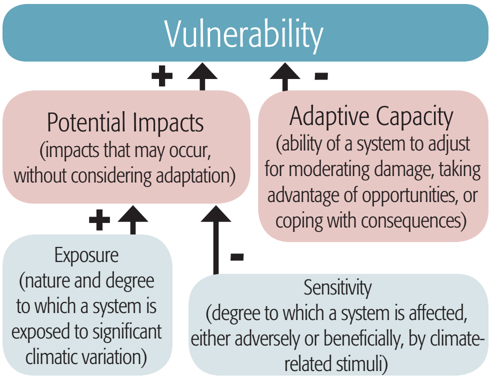
3.2 Connecting the concepts

The resilience concept is very useful for understanding the types of management that undermine ecosystem adaptation. Maintaining an ecosystem's capacity to change and reorganize through the same identity and to absorb sudden shocks is of critical importance (Folke 2002; Holling 1973, 1978; Berkes and Folke 1998). Controlling environmental variability helps achieve short-term stability, but it tends to increase ecosystem vulnerabilities to large shocks, with the potential of causing ecosystems to undergo sudden and unpredictable transformations in structure and function (Holling 1973, 1978; Holling and Sanderson 1996; Berkes and Folke 1998). Of particular concern are policies that disrupt natural cycles of flooding, drought, and fire or that significantly alter trophic interactions (Gunderson and Holling 2002; Gunderson et al. 2006).

The difficulties in identifying benchmarks for resilience (for example, a requisite level of structural diversity or the frequency/magnitude of variation) for most socioeconomic systems, however, make resilience less useful as an analytical tool in climate change adaptation research. Instead, we focus on vulnerability as a proxy for a roughly opposite condition that we can measure more easily based on currently available data. The relationships between the primary components of vulnerability (exposure, sensitivity, and adaptive capacity) are illustrated in Figure 1.

The IPCC approach to analyzing vulnerability (as discussed by Füssel 2007a) integrates assessments of external factors (exposure) and internal factors (sensitivity and adaptive capacity), and considers both socioeconomic and biophysical factors (see Table 1).

FIGURE 1. THE COMPONENTS OF VULNERABILITY



Source: Definitions are from McCarthy et al. 2001.
Note: The signs under the arrows mean that high exposure, high sensitivity, and low adaptive capacity induce high vulnerability.

TABLE 1. FACTORS CONTRIBUTING TO VULNERABILITY

Factors	Socioeconomic	Biophysical
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea level change

Source: Füssel 2007a.

An analysis of system vulnerability provides the basic framework for climate change adaptation (Adger, Arnell, and Tompkins 2005):

- *Reduce exposure:* for example, by relocating a community from a flood-prone area or implementing an emergency alert system
- *Reduce sensitivity:* for example, by planting new crops resistant to drought or creating construction norms for building in hazard-prone areas
- *Increase adaptive capacity:* for example, by raising population education or designing insurance schemes

3.3 Taking an ecosystem-based adaptation approach

When faced with climate-related threats, first consideration is often given to engineering and technological approaches to adaptation, given their permanence and "predictable" function. Augmenting these measures with ecological options, such as coastal and wetland maintenance and restoration, to absorb or control the impact of climate change can be an efficient and effective means of adapting (Huntjens, Pahl-Wostl, and Grin 2010; Jones et al. 2012). For example, research has found the use of mangroves and salt marshes as a buffer against damage to coastal communities and infrastructure to be effective both physically and financially in appropriate locations (Morris 2007; Day et al. 2007). They can also provide biodiversity co-benefits, support fish nurseries, and have carbon sequestration value (Adger, Arnell, and Tompkins 2005; Reid and Huq 2005; CBD 2009).

Ecosystem-based adaptation activities can also use forest management (Bolte et al. 2009; Guariguata 2009; Reyer, Guericke, and Ibisch 2009), agroecosystems in farming systems (Tengö and Belfrage 2004), ecotourism activities (Adler et al. 2013), land and water protection and management, and direct species management (Mawdsley et al. 2009). A 2009 analysis pointed to investing in "ecological infrastructure" (forests, mangroves, wetlands, and so on) as a means of both mitigation and adaptation (TEEB 2009). The report stated that the maintenance or restoration of these ecological resources is of major importance for adaptation, and it highlighted that these resources generate environmental, social, economic, and cultural benefits (see also CBD 2009).

Implementing EBA does involve trade-offs relating to land use and land availability for social, economic, and environmental activities. For example, wetland buffers for coastal protection may need to emphasize silt accumulation, which could compromise the wildlife values and recreational uses of the wetland (CBD 2009; Dudley et al. 2010). An additional consideration is that EBA approaches can be more difficult to implement because they require cooperation across institutions, sectors, and stakeholders and they generate positive externalities, benefiting a wide range of stakeholders (Jones et al. 2012). A major barrier to EBA is the lack of comparable standards and methodologies as applied to engineering approaches, highlighting the need for more discussions between the engineering and ecological communities.

3.3.1 Ecosystem-based adaptation in climate change discussions

The EBA approach is gradually gaining popularity among adaptation, development, and conservation decision makers and practitioners. An analysis of 44 submitted NAPAs showed that the value of ecosystem services was acknowledged in 50 percent of the national proposals. In 22 percent, the use of ecosystem services was included mostly in support of other adaptation activities, including infrastructure, soil conservation, and water regulation (Pramova et al. 2012b). Countries such as Brazil, Costa Rica, Panama, and Sri Lanka have included ecosystem services in their NAPA.

At the sixteenth Conference of the Parties (COP) to the UNFCCC, in Cancun, the parties adopted the Cancun Adaptation Framework as part of the Cancun Agreements. The parties affirmed that adaptation must be addressed with the same level of priority as mitigation. The Framework points to the importance of carrying out economic, social, and environmental evaluations of adaptation options to help the parties enhance actions on adaptation. At the UNFCCC COP 20 in Lima, many G77 countries stated that adaptation is what touches today, tomorrow, and in the medium term the lives of the vulnerable and poor. They pointed to adaptation being a priority, along with the need to identify opportunities to finance it.

The dual role of forests in adaptation and mitigation points to the need to explore opportunities to integrate adaptation practices into mitigation projects focused on REDD+. Considering the work on EBA, there also is an opportunity to explore how the adoption of EBA measures could potentially integrate adaptation and mitigation in efforts to strengthen resilience of other sectors to climate change. A clearer articulation of the contribution of EBAs could inform the National Adaptation Plans (NAPs) that countries are to formulate. The NAPs, established under the Cancun Adaptation Framework, enable parties to identify medium- and long-term adaptation needs and to develop and identify means for meeting these needs. EBA is well suited to be part of medium- and long-term adaptation strategies.

3.3.2 Ecosystem-based adaptation in practice

Due to the wide range of climatic contexts, ecological systems, and affected sectors, there is no universal recipe for designing and implementing adaptation (Füssel 2007b). Smit et al. (1999) offer a number of considerations to take into account, shown in Table 2.

In most cases, an effective adaptation strategy will require concerted and coordinated actions by almost all types listed: individuals, collectives, and national governments. It will require that they address both short-term and long-term challenges, including capacity building for responsive and anticipatory adaptation, and so on.

Consequently, for any given socioecological system, adaptation strategies cannot be imposed as blueprints but must be tailored to the relevant local economic, environmental, political, and cultural context, and they must target the appropriate institutions in order to have the needed impact at the necessary temporal and spatial scales (Locatelli et al. 2008).

TABLE 2. DIFFERENT TYPES OF ADAPTATION

Differentiating Concept	Types of Adaptation
Timing	Anticipatory (or proactive) adaptation takes place before impacts of climate change are observed
	Responsive (or reactive) adaptation takes place after impacts of climate change have been observed
Temporal scope	Short-term (or tactical)
	Long-term (or strategic)
Spatial scope	Localized
	Widespread
Actors	Private adaptation: initiated and implemented by individuals, households, or private companies; usually in the actor's rational self-interest
	Public adaptation: initiated and implemented by governments at all levels; usually directed at collective needs
Function or effects	Retreat, accommodate, protect, prevent, tolerate, spread, change, restore
Form	Structural, legal, institutional, regulatory, financial, technological

Note: Definitions from McCarthy et al. 2001.
Source: Adapted from Smit et al. 1999.

4 FORESTS AND ADAPTATION

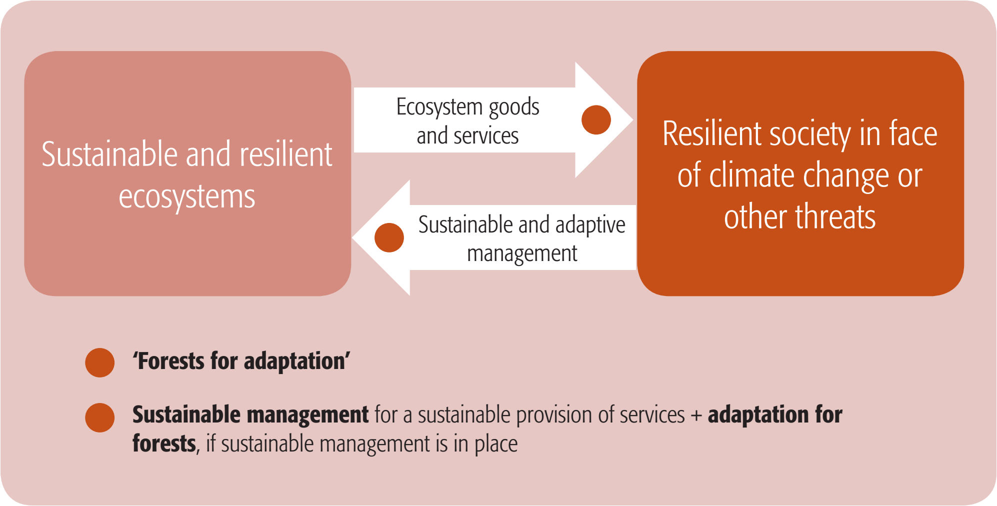
4.1 Two lenses

Within the context of forestry and sectors benefiting from forest ecosystem services (ES), climate change adaptation has two key dimensions that need to be addressed to ensure effectiveness (Locatelli et al. 2010). Figure 2 illustrates these two dimensions as "forests for adaptation" and "adaptation for forests." Our work focuses primarily on the former.

Through the first lens, "forests for adaptation," forest ecosystems provide human societies with a wide range of ecosystem services that reduce, at the local and sectoral levels, the vulnerability to impacts of climate change (particularly changes in the frequency, duration, and intensity of temperature, rainfall, coastal flooding, and hurricanes).

Through the second lens, "adaptation for forests," these climate change variables will have significant impacts on forest growth, species diversity, and ecosystem function. Therefore, in order for human society to continue to benefit from forest ES, adaptation strategies must also reduce the negative climate change impacts on forests themselves.

FIGURE 2. FORESTS FOR ADAPTATION, ADAPTATION FOR FORESTS



Source: Locatelli 2011.

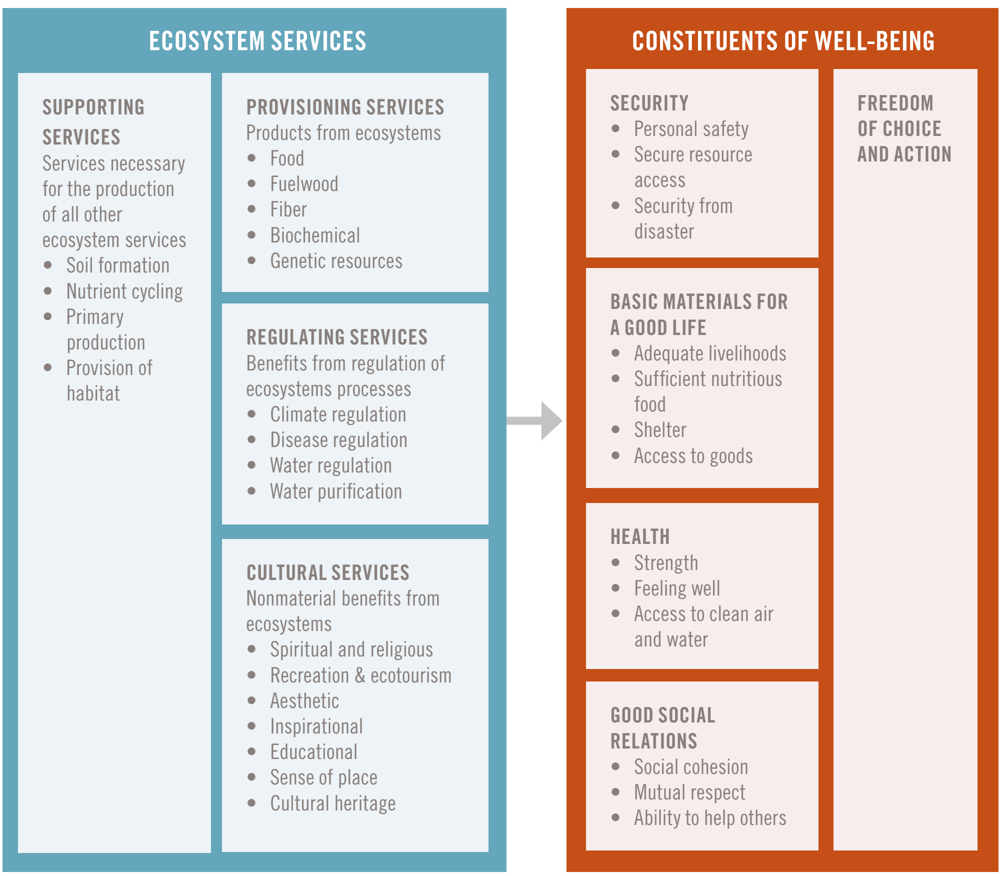
4.2 The role of forests in adaptation strategies

Forests provide valuable and, in some contexts, critical goods and services that reduce the vulnerability of human societies to the impacts of climate change at local, landscape, regional, and global scales. These ES have been classified by the Millennium Ecosystem Assessment into the following categories (MA 2003):

- Provisioning services (also referred to as "ecosystem goods," such as wood, fodder, NTFPs, food, and fuel)
- Regulating services (such as water quantity and quality, microclimate, and soil erosion control)
- Cultural services (such as recreational, spiritual, and religious services)
- Supporting services (necessary for the production of other services, such as primary production, nutrient cycling, and soil formation)

Figure 3 depicts how these four categories of forest ES can contribute to overall societal well-being.

FIGURE 3. THE LINKS BETWEEN ECOSYSTEM SERVICES AND HUMAN WELL-BEING



Source: Locatelli et al. 2008; adapted from MA 2005.

Locatelli et al. (2010) outline the basic argument for EBA concerning forests:

- Forest ES are important for a range of societal needs and are critical for reducing vulnerability to climate change;
- A reduction of these ES presents a threat to societal well-being now and increasingly in the future within the context of climate change;
- Therefore, forest conservation, restoration, and management need to become recognized as a valid and necessary adaptation strategy for this range of sectors.

While there are many examples of spontaneous adaptation to climate change demonstrated in diverse communities (see Mortimore and Adams 2001; Orlove 2005), such efforts—as they rely exclusively on existing institutions and norms—are unlikely to enable societies to cope with the projected unprecedented rates of change and cumulative impacts (recognizing that adaptation in the extreme projection conditions of a 4°C warmer world would not be possible). Future adaptation will require a "deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state" (McCarthy et al. 2001, p. 982). Proactive adaptive strategies that allow for social learning and flexibility in responding to environmental feedback are essential to promote long-term resilience for socioecological systems (Fabricius et al. 2007; Olsson, Folke, and Berkes 2004).

4.3 Evidence of forest services for adaptation

Provisioning and regulating are the main services from forests in terms of adaptation. They help reduce exposure and sensitivity and they increase adaptive capacity. Some illustrative examples of these services are presented in this section.

4.3.1 Ecosystem provisioning services

Provisioning services are also referred to as "ecosystem goods." Overall, ecosystem goods derived from forests can be directly linked to the basic requirements for a good quality of life for many communities in developing countries (income, food security, shelter, and health) (Levy, Babu, and Hamilton 2005; Colfer, Sheil, and Kishi 2006; Colfer 2008). The goods from forests (such as timber, poles, NTFPs, and fuel) help households to diversify their livelihood portfolio. The importance of forest products as an additional source of income and nutrients is accentuated when households are faced with climate-related variability. Climate change often causes shocks; looking at how households address shocks can therefore help in understanding how people adapt to climate change. A difference, however, could be that the means for reducing vulnerability (for instance, use of EBA) could also be sensitive to climate change.

Drawing on a global data set, Angelsen et al. (2014) found that environmental income (that is, income from non-cultivated sources) made up approximately 28 percent of total household income for forest-dependent households. Approximately 77 percent of this income came from forests. The same study found that income shocks have a (weakly) significant and positive impact on absolute environmental and forest income, suggesting that forests may serve as a shock absorber. Using the same dataset, Wunder et al. (2014) found that households rank forest extraction to manage shocks lower than other common alternatives.

The use of forests to address shocks varies by household characteristics and type of shock. Wunder et al. (2014) found that for covariate shocks, such as crop failure, households tend to reduce consumption. Forest extraction is used by households with limited education and land. Forests are often a safety net of last resort and are used when households do not have an alternative. In addition, for many households, while forests may not be the first resource in an emergency, they serve to pay off debt incurred during the emergency.

Other recent studies have indicated that rural populations in developing countries receive on average roughly 25 percent of their income from harvesting NTFPs (including shoots, roots, mushrooms, wildlife, and insects), with such activities being particularly critical income-generating opportunities for women-led households in many poor rural areas (Shackleton et al. 2011). These studies underscore the critical roles that NTFPs play in the overall livelihood strategies of local populations. In some countries, the proportion is much higher: in Lao PDR, for example, NTFPs are estimated to provide roughly 40 percent of household income nationally, with this figure rising to 90 percent among the rural poor (UNDP 2001).

In addition, many rural communities in developing countries rely to a significant degree on timber and charcoal resources as key sources of income (through either direct sale or salaried labor) and as valuable means for recuperating the loss of productive capital following livelihood shocks. Two studies in Tanzania documented the critical roles that forest goods have in meeting the needs of poor rural households when harvests fail (Enfors and Gordon 2008; Paavola 2008). During the drought years of 2005–06, some 85 percent of interviewed households indicated their reliance on forest provisioning services (particularly wild fruits and firewood), which was estimated to provide 42 percent of the total income during these years (Enfors and Gordon 2008). Similarly, for rural households in Malawi, forest products have been shown as key sources of food and income during years of crop failure (Fisher, Chaudhury, and McCuster 2010).

Forest products are important in Central and South America as well, particularly following extreme events such as hurricanes and floods. In Honduras, poor rural households sold forest products to self-insure after being unable to recoup land holdings that were lost due to Hurricane Mitch. Household attributes such as land wealth strongly condition how and when forest resources act as safety nets for the rural poor, especially for the relatively subsistence-insecure (McSweeney 2005).

In Peru, the gathering of NTFPs (such as fruits and palm hearts) was identified as important for coping with crop failures due to flooding. This was particularly important among younger and poorer households and those lacking upland farm plots or rich fish stocks nearby. Clear links exist between asset poverty and NTFP gathering as insurance in certain locations, with NTFPs being the last-resort option for the most vulnerable households (Takasaki et al. 2004).

In Niger, farmer-managed natural regeneration of valuable indigenous tree species on private lands has significantly increased the income and resilience of farmers during years of drought (Tougiani et al. 2009). Building upon local ecological knowledge, through the development of village committees and the establishment of rural wood markets, local stakeholders have been able to improve regulation of local tree harvesting and reduce exploitation by intermediary traders.

In Batu Ampar, Indonesia, diminishing terrestrial timber supplies during the early 2000s resulted in increasing demand and prices for charcoal. Recognizing the increased pressure on local mangroves, forest rangers and nongovernmental organizations (NGOs) encouraged local communities to develop rules regulating the technologies used to cut down mangroves (that is, use of axes rather than chainsaws), as well as restricting which areas could be logged in order to prevent their conversion for aquaculture (by banning logging within 50 meters of the outer margin) (Prasetiamartati et al. 2008).

4.3.2 Ecosystem regulating services

Regulating services cover the regulation of, for example, water, climate, or erosion. Although more difficult to measure, forest regulating services are critical to society at large. All forest types contribute to microclimate regulation and stabilization, sediment retention, and nutrient detention—important services for the resilience of both adjacent ecosystems and agriculture. Furthermore, forests help to buffer society from the brunt of many natural disasters by preventing landslides, moderating the force of waves or wind during storms (Adger, Arnell, and Tompkins 2005), and reducing temperatures during heat waves (Gill et al. 2007).

The discussion here builds on an analysis by Pramova et al. (2012a) of the relationship of forests and trees to regulating services for agriculture, water, and security, focusing on four major forest categories: upland forests and watersheds, agroforested landscapes, riverine/floodplain forests, and coastal mangroves.

UPLAND FORESTS AND WATERSHEDS

A limited number of studies suggest that forested landscapes may increase local base stream flow levels while reducing storm runoff (Ilstedt et al. 2007; Locatelli and Vignola 2009; Pattanayak and Kramer 2001). This buffers agricultural production from the impacts of periodic interruptions in seasonal rainfall and reduces the danger to agricultural production and people's safety from flooding. Pattanayak and Kramer (2001) found that even relatively small increases in base flow have the potential to translate into sizable economic benefits for agricultural production.

These promising results, however, are confounded by other studies. A meta-analysis of watershed services, provided by limited studies in humid natural forests versus planted forests in Central America, indicates that planting does not provide these same hydrological services (Locatelli and Vignola 2009). This may be determined to a certain degree by the age and stand structure of plantings as well as by logging/burning practices that affect the soil itself (Kaimowitz 2005). In addition, in the case of intense and persistent rainfall, increased tree cover has been shown to be correlated with increased flooding, possibly due to vegetation limiting the infiltration of rain into the soil (Bruijnzeel, Calder, and Vertessy 2004; Scott et al. 2004; Liu et al. 2011). Finally, erosion studies have found that soil coverage (understory vegetation and litter layer) may influence the rate of soil erosion more than tree cover does (Scott et al. 2004; Goller et al. 2005).

Given the research summarized here, the levels of certainty with regard to potential benefits from upland forest ES are at times overrepresented in the development of payment for environmental services (PES) schemes (FAO 2004). Increasingly, scientists are concluding that forest impacts on regulatory services are highly dependent on site-specific conditions, such as tree species, topography, geology, soil type and condition, and on issues of scale (Pramova et al.

2012a). They do conclude, however, that natural forest should be seen as the natural baseline for erosion control against which all other land uses should be compared and that reforestation cannot be expected to reverse the damage that deforestation induces on the delivery of ES in the short or medium term (Calder 2002).

AGROFORESTED LANDSCAPES

A substantial body of research has produced evidence on the benefits of agroforestry (mainly on the transfer of nutrients between trees and crops). Although most studies do not draw a link between specific agroforestry systems (tree species and crop types) and climate hazards, a few well-documented exceptions are worth highlighting.

Long-term research has shown that fertilizer tree systems (using nitrogen-fixing trees such as *Faidherbia albida*), when intercropped with maize, contribute to increased drought resilience of maize due to the combined effects of improved soil nutrient levels and increased water infiltration into the soil (Garrity et al. 2010). This research on *F. albida* is supported by widespread indigenous knowledge among farmers in Africa regarding the benefits of this tree (among others) through nitrogen fixation and the supply of fodder (Tougiani et al. 2009).

With respect to key cash crops, recent studies have documented the contributions of shade trees to protecting coffee agriculture from climate variability and climate extremes. Specifically, based on research in high-, medium-, and low-shade coffee sites in Central America, Lin (2007, 2010) found that shade trees have a positive influence on the intensity of fluctuations in temperature, humidity, solar radiation, and soil moisture—all climatic variables to which coffee crops are extremely sensitive.

These studies suggest that, in some contexts, agroforested approaches may be more successful than agricultural intensification in addressing some of the climate change threats to society's agricultural systems (Lin et al. 2008). Furthermore, Verchot et al. (2007) found that more diversified farming systems suffer less from climate shocks when measured over the long term. These conclusions are supported by Venema, Schiller, and Bass (1996), which used a water resources simulation model to demonstrate that a natural resources management policy could bring larger areas under agricultural production with less water and also enhance the sustainability of food production.

RIVERINE/FLOODPLAIN FORESTS

The regulatory services of riverine and floodplain forests, particularly in flood control, are quite different from those of upland forests. Their main function is to delay the passage of flood waters by causing water to meander through circuitous side branches, where physical resistance from vegetation and meandering riverbanks slows the movement of water (Anderson 2008). This gives downstream waters more time to subside. The increased risk of flooding in areas downstream from agricultural or non-forested floodplains is widely recognized as being higher than flooding downstream from forested floodplains (Bates et al. 2008). Due to the tendency of countries to build levees or channel rivers as part of urbanization, and given that most societies disproportionately develop their major centers of habitation and industry in floodplains, the impacts of flooding on floodplains under extreme climate events may be expected to increase (Tockner and Stanford 2002; Ebert et al. 2010).

COASTAL MANGROVES

A number of studies have associated the regulating services of coastal wetlands such as mangroves with protection against cyclones and other storms in Asia and Southeast Asia (Badola and Hussain 2005; Das and Vincent 2009; Tri et al. 1998). As in the case of floodplain forests, mangroves regulate primarily by creating a physical barrier to wave action, stabilizing the seafloor, and altering the slope of the sea flood.

Badola and Hussain (2205) compared the impacts of cyclones on three villages: one protected by mangroves, one lacking mangroves, and one protected by an embankment. They found that the mangrove-protected village had the lowest amount of adverse effects (such as damage to homes) and the highest beneficial values (such as crop yields).The village protected by an embankment was the one most affected by the cyclone. Similarly, Tallis, Ferdana, and Gray (2008) found that potential damage from storms, coastal and inland flooding, and landslides can be considerably reduced by a combination of careful land use planning and maintenance or restoration of ecosystems to enhance buffering capacity. In Vietnam, they found that planting and protecting nearly 12,000 hectares of mangroves cost $1.1 million but saved annual expenditures on dike maintenance of $7.3 million.

In 1999, the state of Orissa in India was battered by a super-cyclone that killed almost 10,000 people and caused a massive loss of livestock (440,000 deaths) and property (almost 2 million damaged houses and over 1.8 million hectares of damaged crops). In all, 12 districts in the state were devastated by the cyclone. Das (2007) examined the role of mangroves alongside all the other factors that affected the impact of the storm in one of the districts that had significant mangrove loss in the past. When the storm hit in 1999, only about 50 percent of the original mangroves remained. The study established that mangrove forests could have significantly reduced the number of human casualties from the super-cyclone. For instance, if the mangrove forests that existed in 1950 had still been in place, 92 percent of the deaths would have been avoided. And if the mangrove forests that did exist in 1999 had not been there, the death toll would have been 54 percent higher than it actually was. The mangroves were also able to significantly lower the degree of house damage in areas within 10 kilometers of the coast and they contributed to reductions in the deaths of large livestock—even though they were less effective in protecting smaller animals like goats and poultry. Das (2007) also estimated that a hectare of mangrove forestland stopped damage worth $43,352 in the district during the super-cyclone. Das also established that the value of a hectare of land with intact mangrove forests was $8,670, whereas a hectare of land after mangroves were cleared sold at $5,000 in the market at that time. Further, the cost of regenerating one hectare of mangroves was approximately $110—many times lower than the benefits that would occur (the $3,670 additional value of a hectare). Also, the cost of constructing a cyclone shelter would have been roughly 10 times more than the benefit offered by mangroves.

One area of misconception relates to the overconfidence that mangroves can protect coastal societies during extreme events in the context of predicted sea level rise. Consequently, mangrove conservation and restoration may in many cases need to be paired with other adaptive strategies such as relocation of human settlements to higher ground. Overall, mangrove conservation or coastal zone planning can rely on the wider contributions to coastal livelihoods that mangroves make (NTFPs for food security, fish habitats, regulation of salinization, protection of biodiversity) in order to convince coastal communities to regard it as a "no-regrets" policy (Mustelin et al. 2010).

4.4 Forests and climate change

Forests are also vulnerable to climate change. There has been extensive work examining the impact of climate change on many aspects of forest ecosystems—ranging from tree growth and dieback, insect outbreaks, and species distributions to the seasonality of ecosystem processes (see studies in Seppälä, Buck and Katila 2009). The effects of climate change have been greater in boreal forests than in other forests (Seppälä, Buck, and Katila 2009). Existing studies on forests and climate change show that the impacts on forests are likely to be pronounced in the time period beyond 50 years (longer than the period of concern in this study). Nevertheless, the potential change in forest characteristics should inform the use of forests for resilience. One generalization that can be made is that the productivity of tropical forests is projected to increase where water is sufficiently available; in drier tropical areas, however, forests are projected to decline.

Although it is beyond the scope of this study and is not examined in detail in the case studies, it is known that in order to use forests to build the resilience of systems, it is necessary to lower the exposure and sensitivity of forest systems to climate change (Seppala, Buck, and Katila 2009). Sustainable management of forests helps maintain and augment the economic, social, and environmental values of all types of forests. Well-managed forests therefore tend to have lower exposure and sensitivity to climate change and accordingly be less vulnerable to climate variability. Sustainable management of forests requires a combination of enabling institutional, socioeconomic, and biophysical conditions. Many of the conditions and institutional arrangements required to enable EBA can also facilitate the sustainable management of forests and trees in a landscape.

5 ANALYTICAL APPROACH

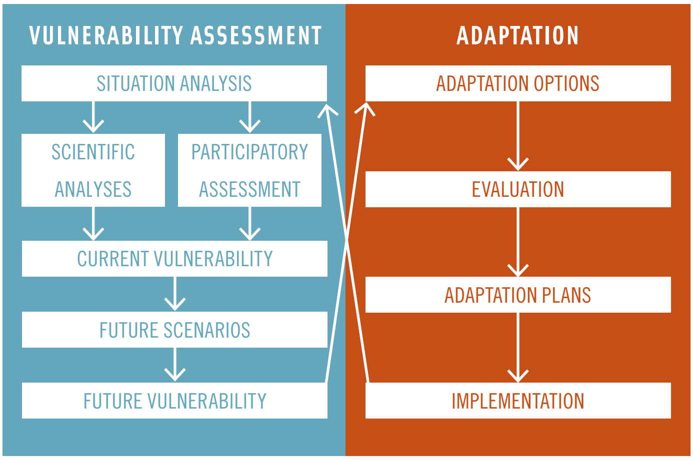
The analysis associated with this work focuses on three cases that explore the use of forests to enhance resilience to climate change in other sectors. This section briefly describes the analytical framework and the approach used in each element of the work. Details on specific methods used for analyzing climate change scenarios and their impacts on ES are described in detail in separate case study–based reports entitled "An Analysis of Climate Change Scenarios and Their Impacts on Ecosystem Services" (Rafanoharana et al. 2012a, 2012b, 2012c).

5.1 Analytical framework

The analytical framework for this study links vulnerability assessment and adaptation (see Figure 4) by bringing together multiple dimensions—a climate change model, the link between land use and climate change (a proxy for sensitivity), the economic or financial dimensions of using EBA, and the policy and institutional context required to implement EBA.

The analytical framework was developed by the Center for International Forestry Research and the Tropical Agricultural Research and Higher Education Center in Costa Rica and is based on work conducted by Turner et al. (2003) and by Metzger, Leemans, and Schröter (2005).[3] It seeks to identify current and future social and environmental vulnerabilities and to draw

FIGURE 4. ANALYTICAL FRAMEWORK



Source: CIFOR 2010.

3. More information on the TroFCCA project can be found at www.cifor.cgiar.org/trofcca.

direct connections to planned climate change adaptation. This approach has been applied to the analysis of vulnerability and the design of adaptation strategies in diverse ES and different contexts, such as NTFP in West Africa and forest hydrological services in Central America. The framework is designed to analyze the vulnerability of landscapes with both social and ecological components and to integrate climate variability, climate change, and other threats (TroFCCA 2012). It fulfills the general purpose of vulnerability assessments and informs stakeholders about adaptation options (Metzger and Schröter 2006).

5.2 Site selection

Three country case studies were selected for this activity—Burkina Faso, Honduras, and Lao PDR—to examine the linkages between forest and trees and resilience in different sectors. The sites were selected based on considerations for adaptation in the country's climate change strategy and exposure to climate change, interest in and demand for analysis on potential engagement in EBA, opportunity to inform ongoing dialogue, and the lack of ongoing analytical work on the same topic that would be duplicated. In Burkina Faso, the sector of interest was energy; in Honduras, it was water supply; and in Lao PDR, smallholder agriculture.

5.3 Climate change and land use impact assessments

All case studies used climate change projections for 2030 and 2080 based on the TYN SC 2.03 dataset developed by the Climate Research Unit at the University of East Anglia (Mitchell et al. 2003).[4] This dataset establishes a global historical baseline of climate variables for the period 1951–2000 and 16 possible climate change projections resulting from four global climate models (GCMs).[5] The four emissions scenarios reflect different global development pathways, with distinct combinations of predicted economic growth, technological innovation, economic equity, and environmental quality.

In all case studies, the climate change models mentioned were integrated in the Lund-Potsdam-Jena dynamic global vegetation model (Smith, Prentice, and Sykes 2001; Sitch et al. 2003) to identify the possible impacts of climate change on the net primary productivity[6] (NPP) of natural ecosystems, water runoff, and fires. The model helps identify the possible impacts of

4. These data are publicly available at www.cru.uea.ac.uk/cru/data/hrg/timm/grid/TYN_SC_2_0.html.
5. There are additional GCMs, but these four were identified as state of the art by the IPCC in the Third Assessment Working Group 1 Report (McCarthy et al. 2001).

6. NPP is considered a useful proxy for how forests, as ecosystems, would be subject to both spatial and temporal shifts with climate. Its use, however, does not cover spatial shifts where entire vegetation zones could shift latitudinally or with respect to elevation. The shortcoming of not including spatial shifts is briefly discussed in the Burkina Faso case. The spatial shifts are not elaborated on because the evidence is mixed on how tropical forests will respond to climate change. Some research suggests that, because deforestation creates barriers to migration of tree species, there is an increasing likelihood of severely influencing the distribution of certain tree species and limiting how they adapt to climate change. What is evident, however, is the importance of adapting forest management in order to internalize these new climate change–driven realities.

climate change within the study area based on a range of hydro-climatic variables. This model is derived from the BIOME family (Prentice et al. 1993; Haxeltine and Prentice 1996), and it models key ecosystem processes that govern terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a modular framework (Sitch et al. 2003; Gerten et al. 2004), using data from internationally recognized datasets.

The primary outputs from this analysis represent how baseline and future climate scenarios are likely to interact with soil type and carbon dioxide (CO_2) to lead to different levels of the following key ecological processes:

- Net primary productivity is a measure of total growth in biomass;
- Runoff, measured at gauging stations on rivers, is equivalent to the difference between precipitation and evapotranspiration, averaged over the catchment upstream of the station;[7]
- Fire fraction is a measure of the proportion of vegetation that is exposed to fire over the course of a year and is represented as a fraction of total land area (0–1).

In addition, Holdridge life zones were used to analyze how vegetation types (Holdridge 1947) may change in the future under different climate change scenarios. The Holdridge life zones describe the suitability of vegetative classes based on precipitation and temperature, so any alterations in distributions of rainfall and temperature under future climate change scenarios can be expected to result in qualitative shifts from one "life zone" to another.

Globcover land cover maps for years 2005 and 2009 were used to derive the historical land cover change in the three case studies.[8] In addition, the Integrated Model to Assess the Global Environment (IMAGE) version 2.2 data were used in this study to develop scenarios from the combination of the impacts of climate change and land use change for short-term (2030) and long-term (2080) projections. The IMAGE 2.2 model is a "multi-disciplinary, integrated model designated to simulate the dynamics of the global society-biosphere-climate system" (van Vuuren and Bouwman 2005). These data were combined with global maps of land use—the GLC 2000 database at a resolution of 1km.

For example, when the IMAGE 2.2 dynamic integrated assessment model was used for the study in Honduras, different scenarios were developed to assess the impacts of climate change and land use change on soil erosion in the Guacerique watershed. The analysis examined whether land use and land management could offset the negative impacts of climate change on soil erosion.

In all the case studies, the climate change modeling work did not take into account extreme events such as extremely hot and dry years, during which fires can affect larger areas than normal. Global studies on the impact of climate change on fires show that our study sites may experience a small decrease in fire probability, frequency, or potential (Krawchuk et al. 2009; Liu, Stanturf, and Goodrick 2010; Moritz et al. 2012), a small increase (Scholze et al. 2006), or a small-to-medium increase (Alo and Wang 2008).

7. According to Rafanoharana et al. (2012a, 2012b, 2012c), Gerten et al. (2004) demonstrated that the Lund-Potsdam-Jena model showed comparable skill to existing global hydrology models in predicting global runoff patterns.

8. Data source: ESA / ESA Globcover Project, led by MEDIAS-France/Postel (postel.mediasfrance.org/en/PROJECTS/Preoperational-GMES/GLOBCOVER/).

In Burkina Faso, the simplified land classification used as part of the Holdridge life zones provides limited information on how the change in ecosystem type changes vegetation, pointing to an area requiring additional work. The climate change modeling for the Honduras study does not take into account extreme events such as hurricanes and severe rains. It is known that climate change will modify the erosivity of rainfall, which is of major concern to water users affected by sediments (such as dams). Erosion may increase due to increasing rainfall intensity or extremely wet years. This, however, is not reflected in the climate change scenarios. Similarly, in Lao PDR extreme events such as floods were not taken into account in the climate change scenario.

5.4 Economic valuations of ecosystem services

Conventional analytical approaches that examine the potential of ecosystem-based adaptation efforts often use the traditional estimation of costs and benefits in a project context. For EBAs, this approach has various shortcomings. [9] It requires a significant amount of data that are often difficult to obtain or seldom quantified (such as opportunity costs and ecological and socioeconomic benefits). For most projects, cost-benefit assessments often involve using information based on estimations of project managers and include qualitative assessments of opportunity costs and benefits. Moreover, there are often difficulties in using and comparing different sources of costs because some projects use one-off costs while others use recurrent costs without defining the time frame. So, while it would be optimal, a cost-benefit analysis is not used here.

In the **Burkina Faso study**, a cost analysis of the implementation of two strategies—a modernization strategy of the wood energy value chain and a liquefied petroleum gas (LPG) strategy—under three scenarios using a simulation model was developed as a spreadsheet for the period 2013–30. The period is divided into an initial stage of 2014–18 and a consecutive stage of 2019–30. The costs for the LPG strategy, however, do not reflect the costs associated with enhancing the resilience of the hydrocarbon storage infrastructure or the risks associated with climate-related risks of the transportation and port infrastructure in other countries.

The three scenarios were base (business as usual), optimistic, and pessimistic. The base scenario assumes no impact of climate change on forest productivity, population growth of 3.4 percent per year in urban areas and 3.1 percent per year in rural areas, and regression of forest land area by 0.54 percent per year. The main difference between the optimistic and base scenario is a positive impact of climate change on forest productivity due to increased rainfall and a fertilizer effect of CO_2, resulting in a 15 percent increase by 2050 compared with 2013. The pessimistic scenario differs from the base scenario in that it assumes a negative impact of climate change on forest productivity due to high temperatures and high rainfall variability, leading to a decrease of 25 percent by 2050 compared with 2013.

For the **Honduras study**, the economic analysis consists of estimating the impact of the proposed Guacerique watershed management plan on key ES and the resulting cost savings to the national water utility under two climate change scenarios. The scenarios were built using a range of model output data taken from the Regional Analysis Tool

9. See www.ecologic.eu/sites/files/project/2013/2345_eba_ebm_cc_finalreport_23nov2011.pdf.

(BETA version) developed by the Pacific Climate Impacts Consortium that was ordered to provide 10 and 90 percentile values representing ranges of extremes (Pacific Climate Impacts Consortium n.d.). Expert judgment was used to estimate the impact of specific management options on water supply outcomes under climate change. (Expert judgment has been successfully used in the past to address resource management issues under the uncertainty of climate change; see Hagerman et al. 2010; McDaniels 1995; McDaniels et al. 2012; Morgan et al. 2001.)

In the case of the **Lao PDR study**, the values of key ecosystem services are presented in terms of the value of annual benefits accruing (or potentially accruing) to local stakeholders and are specified by major land use category (dry dipterocarp forest, mixed deciduous forest, paddy). All analysis regarding the ES comes largely from secondary data. A household survey was implemented in order to represent some of the differences in livelihoods and the reliance on different ES (as well as other sources of income and expenditure) by different types of households and villages. These surveys were completed for three wealth groups in each of three villages, and they covered a number of thematic areas, including demographics, livelihood activities, income sources, assets, and food security. From analysis of market or replacement values of these ecosystem services, an estimated (although incomplete) valuation of dry dipterocarp forest (DDF) was calculated. Both the household and most of the secondary data sources are based on data collected in single snapshots of time or single locations.

One of the main methodological challenges identified in this study is that of collecting reliable consumption, use, and sales data for NTFPs gathered by communities. While an attempt has been made to do so through the survey, the focus group data indicate that the data elicited through surveys may significantly underestimate these values. Further, there were several ecosystem services for which no data were available.[10]

In terms of the household socioeconomic survey, in Lao PDR the limited household sample within each village wealth category and non-randomized sampling design meant that the results cannot be regarded as statistically representative of these groups, and they should be interpreted in conjunction with other data sets available. Analyses of differences spanning villages or wealth groups similarly cannot be regarded as statistically representative of their class or whole village, but their larger sample size (N=12) suggests that where trends appear significant, these results may warrant further examination.

10. The ecosystem services for which data were not available include:

- Provision of drinking water for livestock consumption
- Provision of habitat for biodiversity in general, as well as the flora and fauna involved in natural pest regulation and barriers to the spread of diseases and the provisioning of honey and pollination services for many plants, both domesticated and not
- Soil micronutrient uptake
- Microbial diversity for soil health
- Local temperature and climate regulation during heat waves that protect humans and livestock, and damage to a range of plants used by humans
- Cultural and religious values
- Recreational and aesthetic values
- Genetic diversity values
- Medicinal values

5.5. Governance analysis

A governance analysis was undertaken for the case studies of Burkina Faso and Honduras. Data for the governance analysis were collected through primary and secondary sources. Stakeholder workshops allowed for primary data collection on local conceptions of governance, stakeholder views on governance gaps, and other information related to the current governance context to promote EBA options. This information was supplemented with secondary sources on specific laws, institutional mandates for key stakeholders, and the case study area. The forest governance evaluation framework developed by the U.N. Food and Agriculture Organization (FAO/WFP 2011) was used as a guide in developing the analysis.

6 CASE STUDY ANALYSES

6.1 Burkina Faso—Forests and energy

Burkina Faso is a landlocked country located in the middle of the West African Sahel region and occupying over 274,000 square kilometers. It has arid and semiarid ecosystems. Although these ecosystems have a much lower biomass per unit area than tropical rain forests, they cover a very large area (dry forests cover 43 percent of the land surface of Africa).[11] With limited natural resources and a highly variable climate, food security and economic opportunity remain a challenge for Burkina Faso. Roughly 80 percent of employment is linked to subsistence farming. The country's soils tend to be poor in nutrients, have low water-holding capacity, and are largely degraded. When rainfall declines, dust storms occur, or the temperature spikes, food supplies and yields are immediately affected. These fragile conditions have kept Burkina Faso at the bottom of the U.N.'s Human Development Index, ranking 162 out of 169 countries, with 46 percent of the population below the poverty line. Burkina Faso is prone to chronic drought, flash floods, wind storms, and disease outbreaks. Measures to improve water retention and cultivation resilience to climate variation have started, but they remain local and small-scale.[12]

With sporadic rains and poor water retention in soils, "quasi-drought" conditions have plagued Burkina Faso since the early 1970s. In contrast, the wet season is characterized by heavy and often relentless rain, wreaking havoc on the country's poorly constructed informal settlements and degraded landscape, disturbing the entire water sector, and destroying or reducing infrastructure services. Over the past 30 years, Burkina Faso has experienced repeated severe flooding.[13]

Sectoral priorities in the country, from an adaptation standpoint, include forests. Energy, although not identified as a priority sector, remains of concern because of the role it plays in food security and the use of wood for energy production and because of opportunities to indirectly tackle adaptation of forests while generating resilience in the energy sector.

Burkina Faso is challenged to achieve energy security by its high population growth rate and strong dependence on fuelwood and imported petroleum products.[14] The country is characterized by a low level of diversity of energy sources, with a predominance of systems that are vulnerable to climate change (firewood) or to fluctuating oil prices on the world market.[15] One of the main adaptation options for the energy sector is to promote improved "green" stoves and other alternative energy equipment.

11. www.forestcarbonpartnership.org/sites/forestcarbonpartnership.org/files/Documents/PDF/June2012/R-PP%20Burkina%20English-%20FINAL%20June%202012.pdf.
12. sdwebx.worldbank.org/climateportalb/home.cfm?page=country_profile&CCode=BFA&ThisTab=Dashboard.
13. sdwebx.worldbank.org/climateportalb/home.cfm?page=country_profile&CCode=BFA&ThisTab=NaturalHazards.
14. sdwebx.worldbank.org/climateportalb/doc/USAIDProfiles/Africa_West_AfricaRegional_and_Country_Profiles_Final_with_new_template.pdf#page=67.
15. www.helio-international.org/VARBurkina%20Faso.En.pdf.

The scope of the study here was to assess the contribution of "forests" (savannas, woodlands, and fallows) to the household energy sector's adaptation to climate change. The approach examines the subsector of domestic fuels and, more particularly, wood energy to clarify how forest ecosystems can contribute significantly to the country's energy needs while actively contributing to the reduction of the vulnerability of the wood energy value chain. The recommendations aim to help Burkina Faso's energy system withstand shocks, including the consequences of climate change, which are forecast to be fairly severe for the next 50 years.

The methodology used attempts to quantify the adaptation potential from forests in order to facilitate its integration into national action plans. In addition to describing the current situation in the wood energy subsector, the case study includes a prospective analysis that considers the vulnerability of the eco-geographical zones to climate and anthropic factors. A model is developed to help examine the current and projected impact of climate change on the wood energy value chain in order to identify adaptation strategies and focus on solutions oriented to forest ecosystems. Tied to the climate change model is a land use change model focused on Ziro-Sissili provinces, the primary sources of wood energy and charcoal for Ouagadougou. The final part of the analysis focuses on the implementation aspects of the proposed adaptation strategy by presenting an action plan and associated costs. The resulting strategy is aimed primarily at policy makers but also at civil society.

6.1.1 Climate change and potential impact on wood energy

CLIMATE SCENARIOS

Climate projection simulations performed for Burkina Faso (MECV 2007) predict an increase in average temperatures of 0.8°C by 2025 and 1.7°C by 2050. This is to be accompanied by a seasonal variation. If in December, January, August, and September it is noticeably warmer, the months of November and March have low increases. Simulations for the region of Ziro-Sissili (Rafanoharana et al. 2012b), using four global climate models based on 16 emission scenarios, give a more pessimistic picture. The increase in average annual temperature by 2030 compared with the reference period from 1961 to 1990 is in the range of 0.73°C to 1.58°C. The same models reveal an increase of between 1.37°C and 5.33°C by 2080. Monthly temperature projections for Ziro-Sissili show a consistent upward trend for the 16 scenarios. Months between February and May are the most affected by the potential increase in temperature (of more than 25 percent).

Climate projections on rainfall for West Africa and the Sahel are characterized by a high degree of uncertainty (IPCC 2001; OECD/SWAC 2009), mainly because of the complexity of the climate system in the region and the respective limits of current climate models. This also is evident in the simulations of rainfall for the region of Ziro-Sissili, in which annual average rainfall projections for 2030 vary between minus 58.20 mms/year and plus 60.78 mms/year, and the projections for 2080 are between minus 146.58

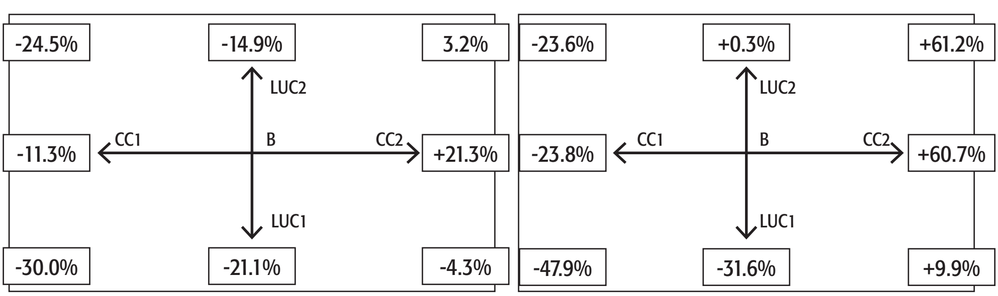
mms and plus 121.84 mms/year (reference period: 1961–90) (Rafanoharana et al. 2012b). For rainfall, strong interannual and seasonal variability is expected. In some models, July, August, and September are likely to be affected by decreases of approximately 20–30 percent, while the rainfall in November will increase by 60–80 percent. Results from Rafanoharan et al. (2012b) show a decrease and an increase, respectively, with a particularly wide range for the months of July and September.

THE CASE OF NET PRIMARY PRODUCTIVITY

In Burkina Faso, the level of reliance on biomass for energy points to the importance of understanding the relationship between climate change and net primary productivity. Increasing or maintaining current levels of NPP could help reduce households' sensitivity to climate change. IMAGE version 2.2 data were used by Rafanoharana et al. (2012b) to develop scenarios from the combination of the impacts of climate change and land use change for short-term (2030) and long-term (2080) projections, and they were combined with current and future projections of land use change. The analysis for 2030 revealed that the negative impacts of climate change on NPP (minus 11.3 percent) are not offset by the most optimistic scenarios used for the set of land use scenarios (minus 24.5 percent). The positive impacts of climate change (plus 21.3 percent) are almost lost because of land use change (minus 4.3 percent). The same holds in 2080: the negative impacts of climate change (minus 23.8 percent) are not offset by the most optimistic scenarios in the set of land use scenarios (minus 23.6 percent), and the positive impacts of climate change (resulting in a 60.7 percent increase in net primary productivity) can be almost lost because of land use change (changing the gains in net primary productivity from 60.7 percent to 9.9 percent). (See Figure 5.)

Accordingly, at a minimum all planning has to account for the land use change (LUC2) of between minus 24.50 percent and plus 3.2 percent in 2030 and between minus 23.6 percent and plus 61.20 percent in 2080. If the drivers of land use change are not addressed, however, planners need to expect changes of net primary productivity (as seen with LUC1) of between minus 30 percent and minus 4.3 percent in 2030 and between minus 47.9 percent and plus 9.9 percent in 2080.

FIGURE 5. SCENARIOS OF IMPACTS ON NPP FORESTS IN BURKINA FASO FOR CLIMATE AND LAND USE CHANGE PROJECTIONS (2030, 2080)



Change in NPP is compared with the baseline (B) for two contrasting climate and land use change scenarios: CC1 - CSIRO2.B2A and CC2 - HAD3.B2M; LUC1 - IMAGE.B2 and LUC2 - IMAGE.B1 in 2030 (on the left) and CC1 - CSIRO2.B2A and CC2 - CGCM2.A1FI; LUC1 - IMAGE.B2 and LUC2 - IMAGE.B1 in 2080 (on the right)

6.1.2 Measures to address constraints

There are several possible approaches to reduce vulnerability (Adger, Arnell, and Tompkins 2005), including:

- Reducing exposure to climate change and its immediate effects (for example, by increasing the area under trees)
- Reducing sensitivity to climate change (for example, by using drought-resistant species)
- Maintaining or increasing adaptive capacity (for example, by improving the well-being of the population)

Efforts to build resilience in the energy system are distinguished by different energy sources. According to our analysis, a strategy to reduce the vulnerability to climate change of the wood energy subsector that focused purely on wood energy is not feasible. Interventions on the supply side must be accompanied, at a minimum, by measures to reduce demand. The analysis, therefore, examines two types of development strategies for the subsector by 2030.

First, a strategy to modernize the wood energy value chain, which:

- Is based primarily on the sustainable management of forest ecosystems and optimization of the other links in the value chain
- Promotes increased energy diversification with the promotion of butane gas as a supplementary measure
- Aims to achieve coverage for 90 percent of the energy needs of rural households from wood energy and 60 percent of urban households' needs

This strategy is an EBA approach. It uses management of forests, rationalization of wood supply, and efficient wood use to try to meet the growing demand for energy to help adapt to the consequences of decreasing net primary productivity. The EBA approach also generates social, economic, and environmental benefits (SIB 2012).

Second, a strategy focusing on LPG, which:

- Is based largely on the supply of LPG;
- Targets the coverage of 60 percent of the energy needs of rural households from wood energy and 30 percent of urban households' needs

An action plan is proposed for the period 2014–18 for modernizing the wood energy value chain (which also requires formalization of the value chain). The action plan takes into account the available human resources and the planning carried out by ongoing projects/programs. It involves putting under management a total area of approximately 805,000 hectares (ha) of forest. In addition, it is planned to create 38,000 ha of plantations, as well as the protection of 260,000 ha.

The action plan includes initiating the distribution of improved cookstoves on a large scale (390,000 stoves) and promoting the use of butane gas to 160,000 households. As an additional measure, it is scheduled to enhance the installation of biogas units. This strategy requires the setting up of an effective control system coupled with a tracking system and a system of monitoring and evaluation. Implementation of necessary systems will need to be supported by training and retraining programs as well as by investments, particularly in infrastructure and equipment.

6.1.3 Economic case for forests

The total cost of implementating the action plan reaches 53.07 billion CFA francs (FCFA), equivalent to $109.54 million. The costs of technical operations amount to 36.11 billion FCFA (68 percent, $74.54 million) and the training costs are 3.36 billion FCFA (6 percent, $6.95 million). For the funding of facilities and small equipment, the action plan provides for investments on the order of 5.45 billion FCFA (10 percent, $8.31 million). Operating costs, including monitoring and evaluation for the implementation of the action plan, amount to 8.15 billion FCFA (16 percent, $16.81 million).

The cost analysis of the implementation of the two strategies under three scenarios (business as usual, optimistic, pessimistic) is based on a simulation model for 2013–30. This period covers an initial stage from 2014 to 2018 and a consecutive stage 2019–30. The forest area put under management varies between 2.1 million and 4.2 million ha, meeting approximately one-third of the wood energy strategy. The plantation area established is between 185,000 and 270,000 ha, depending on the scenario. The total cost in 2030 for the implementation of the modernization strategy of the wood energy value chain varies between 232.2 billion FCFA ($479.35 million) in the optimistic scenario and 306.3 billion FCFA ($632.32 million) in the pessimistic scenario. In addition to average annual costs, investments range between 13.7 billion and 18 billion FCFA (between $28.28 million and $37.16 million).

The LPG strategy simulation is based on approximately 2.2 million households being supplied by butane gas and the distribution of 950,000 improved cookstoves. The total costs are significantly lower than those of the modernization strategy and range from around 170 billion to 220 billion FCFA ($350.94 million to $454.16 million). The total annual costs of the LPG strategy are lower than the optimistic scenario for the wood energy strategy.

The EBA approach can provide additional co-benefits. The sustainable production of wood energy could contribute to the preservation of forests and woodlands while maintaining the associated functions. Unlike other energy sources requiring more sophisticated technologies, woody fuels generate employment and revenue at the local level, especially for the poorest and most disadvantaged groups, and generally these job opportunities have low barriers to entry. Woody fuels, especially charcoal, are multipurpose and have a high potential for technical innovations in terms of conversion and improved combustion. In addition, domestic woody fuel products contribute sustainably to neutral energy supply in carbon and therefore are a key factor in the implementation of growth strategies with a low carbon footprint. Woody fuels produced locally also reduce dependence on limited fossil fuels. Therefore, in addition to gains in efficiency through innovations, promotion of woody fuel offers indirect benefits such as currency savings and a reduced economic dependence of the country. The modernization of the woody fuels sector, and in particular the introduction of more efficient combustion technologies, also contributes significantly to a reduction in respiratory problems and even deaths due to internal domestic long-term pollution.

6.1.4 Institutional changes needed

Several institutional changes are needed to facilitate the use of forests to enhance resilience in the wood energy subsector. This section briefly summarizes those measures and highlights how they fit within the vulnerability framework.

Production of wood energy needs to give priority to the protection and management of forestry and forest areas of the country to reduce the sensitivity of the system to climate change. The associated actions also contribute to mitigating climate change, an additional benefit to the reduction in sensitivity. Priority actions to be carried out will be related to the demarcation of forests, the definition of access and management regulations in a concerted manner, and the organization of village structures to enforce these rules based on consensus. Achieving the production of wood for energy will require decentralized and participatory management at all selected priority sites, planning, and the development of management plans. There also will be new needs for the mobilization of human and financial resources, including allowing rural communities to become involved in forestry with the resources they can expect from national and international sources.

Modernization of the wood energy value chain implies preconditions, including the revision of targets in household energy. Indeed, until now, all policies and strategies referred to progressive substitution of woody fuels by other sources, primarily butane gas. In order to mobilize support for modernizing the value chain, it will also be important to encourage policy makers to review their policies and strategies in the direction of promoting a combination of different energies. A political dialogue with key representatives at national and regional levels on the potential benefits of the modernization of the wood energy value chain is instrumental.

Implementation of this modernization effort will require numerous institutional measures, including:

- Improve sustainable production of wood energy to reduce the sensitivity of the system by promoting participatory management of natural forests and increasing the area under plantations and agroforestry;
- Improve exploitation and processing of wood energy to mostly enhance the adaptive capacity of the system by building the capacity of local actors, increasing efficiency of resource use, and testing and disseminating innovative methods to use agricultural residues;
- Improve transportation and marketing of wood energy for better adaptive capacity of the system;
- Improve the use of wood energy to reduce the sensitivity of the system by testing models of improved household cookstoves and disseminating them in urban and rural areas;
- Strengthen the framework conditions to mostly augment the adaptive capacity of the system by supporting the forest administration in the implementation of differential taxation of wood; adapting the regulatory and fiscal framework to develop a rural wood energy market and urban wood energy market; establishing an effective monitoring system and tracking system; decentralizing control by integrating local authorities and stakeholders in the system; ensuring regional planning involves modernizing the value chain; creating a wood energy unit to enhance coordination; developing regional wood energy supply directives to rebalance the national supply/demand in wood energy; and improving information use in decision making and dissemination of up-to-date information.

Implementing the plan will require the engagement of all the key actors. Financing for the modernization strategy will need to be obtained from the state budget, the budget of the local authorities, the Forestry Development Fund, contributions from grassroots communities, the private sector and NGOs, and international development partners.

6.2 Honduras—Forests and water

Honduras is considered one of the most vulnerable countries to climate change in Latin America, and it figures third on a global climate risk index that uses exposure and vulnerability to extreme events[16] for the period 1991–2010 as a proxy (Harmeling et al. 2012). Honduras experienced an average of 56 extreme events during this period, an annual average of 327 deaths (approximately 5 out of every 100,000 inhabitants), and annual average losses close to $662 million (PPP dollars) or 2.93 percent of the gross domestic product (Harmeling et al. 2012, p. 6). Honduras ranks high on the index due to Hurricane Mitch, which caused 80 percent of all the losses and fatalities recorded for the 20-year period (Harmeling et al. 2012, p. 8).

The government of Honduras has identified the Choluteca River basin and the watersheds that provide drinking water to Tegucigalpa—which includes the Guacerique watershed—as one of the areas most vulnerable to climate change (SERNA 2000). The Guacerique catchment services 25 percent of the water supply connections in Tegucigalpa, a city that is home to approximately 13 percent of the total population in Honduras (about 1.05 million people) (Reyes 2006).[17] According to the Tropical Forests and Climate Change Adaptation project (TroFCCA 2009), the primary livelihoods in the Guacerique watershed include subsistence and small-scale commercial agriculture (primarily vegetables), subsistence cattle farming, and forestry.

16. There is no unique definition of climate extreme events (Beniston and Stephenson 2004). Here, the study of Harmeling et al. (2012) used Munich Re's GeoRisk definition, which is related more to damages registered in disaster databases than to a climate-based definition.

17. Tegucigalpa here refers to the twin cities of Tegucigalpa and Comayagüela, which are governed by a single municipal government, the Municipality of the Central District.

Land use change in the Guacerique watershed over the last 20 years has occurred in an unregulated fashion (despite an existing legal framework). Urban expansion has already started to penetrate the Guacerique watershed (UNDP 2010). An environmental vulnerability assessment of the main river basins in Honduras concluded that the river basin with the Guacerique watershed (the Choluteca river basin) is one of the most deforested in the country. Water managers are currently seeking to combine ecosystem- and infrastructure-based solutions to the water supply challenges they face.

In Honduras, the scope of the study is to understand the potential for using forest EBA to adapt to the potential impact of climate change on the Guacerique watershed. The case study seeks to integrate climate change and ES modeling at the watershed scale with an economic analysis of the impacts of watershed management policies on water quality and quantity under high and low climate change scenarios. The analysis did not include data on extreme events. It aims to inform policy makers about the economic contributions of forest ES in the watershed. Several research methods were used to generate data on the future climate, governance, the economic impact of management options, and current and future system vulnerability.

6.2.1 Climate change and potential impact on drinking water supply

CLIMATE SCENARIOS

All 16 climate change scenarios predict a future increase in temperatures in the case study site of between 1.1°C and 5.3°C in 2080. Future precipitation trends are uncertain, with a range of relative changes from minus 34 percent to plus 9 percent in 2080. However, more scenarios show a decrease than an increase. Another study, using a set of 136 climate change scenarios in Central America, showed that precipitation is very likely to decrease in our study site during 2070–99 under high emission scenarios (Imbach et al. 2012). A global analysis of climate change scenarios concluded that Central America is a tropical climate change hotspot (Giorgi 2006).

Uncertainties about future precipitation have major implications for predicting the impacts of climate change on ES and livelihoods (Kandlikar, Risbey, and Dessai 2005). This makes it difficult for scientists to communicate impacts (Patt and Dessai, 2005) and for decision makers to plan for them. However, some decisions may provide adaptation benefits under a wide range of climate scenarios, and flexible and adaptive strategies can be developed that are more likely to be resilient to uncertainty (Dessai and Wilby 2011).

ECOSYSTEM MODELING

When using a coupled climate-vegetation-soil-water model with the 16 climate change scenarios, all scenarios predict an increase in the productivity of natural vegetation (range of changes between 16 and 62 percent in 2080). The scenario with the highest decrease in precipitation shows the lowest increase in productivity, but this increase is still positive. Additional research is needed to understand the reasons of productivity increase in spite of precipitation decrease, perhaps linked to temperature increase. Another global study found limited changes in ecosystem productivity in Central America, much lower than in this study (Scholze et al. 2006). However, most global studies at a coarse scale cannot reflect the diversity of climate in the narrow strip of Central America.

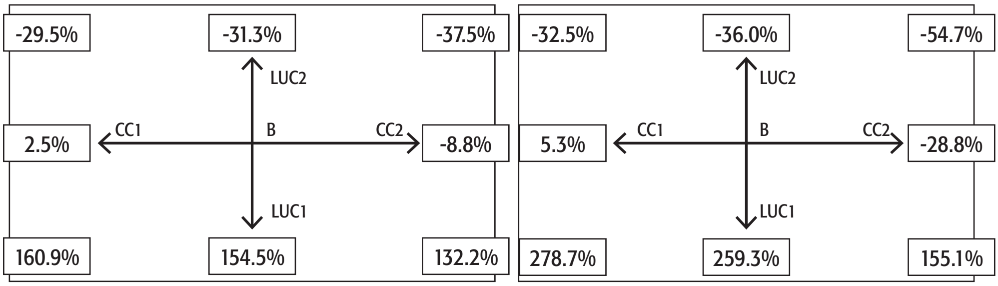
Model results show that water runoff is predicted to decrease in almost all scenarios, with relative changes ranging from minus 31 percent to 0 by 2080. Similar results were found in the regional study that used 136 scenarios and another vegetation model (Imbach et al. 2012): runoff is very likely to decrease in 2070–99. Even though precipitation decrease is not predicted in all cases, the certainty of temperature increases results in runoff decreases in all scenarios. This has major implications for the users of surface water in the study site.

THE CASE OF SOIL EROSION

Climate change will modify the erosivity of rainfall, which is of major concern to water users and infrastructure affected by sediments (such as reservoirs and drinking water systems). The projected change in rainfall erosivity ranges from minus 28.8 percent to plus 5.3 percent by 2080 (see Figure 6). Most scenarios show a decrease in erosivity due to decreasing rainfall, but it should be highlighted that our climate change scenarios consider only changes in mean precipitation, not in extreme events. Erosion may increase due to increasing rainfall intensity or extremely wet years. A study by Aguilar et al. (2005) suggests that the intensity and frequency of extreme precipitation events have been increasing in the last decades.

The major land cover changes observed in our study site between 2005 and 2009 were an increase in open (from closed) forests and a decrease in mosaic croplands, mosaic forests or shrublands, and herbaceous vegetation. One of the four global scenarios of land use change in Central America suggests a strong decrease in areas of natural vegetation in 2080, but the others show similar or larger areas of natural vegetation in 2080 compared with the baseline. Using land use and climate change scenarios specifically for the Guacerique watershed, we found that the potential benefits of decreased rainfall erositivity in 2080 (minus 28.8 percent) may easily be lost by inappropriate land use,

FIGURE 6. EXTREME SCENARIOS OF IMPACTS ON SOIL EROSION IN HONDURAS FOR CLIMATE AND LAND USE CHANGE PROJECTIONS (2030, 2080)



Change in soil erosion compared with the baseline (B) for two contrasting climate scenarios (CC1 – PCM.B2A and CC2 – HAD3.A1FI) and two contrasting land-use change scenarios (LUC1 – Scenario A and LUC2 – Scenario D) in 2030 (left) and 2080 (right)

Notes: LUC=Land Use Change; CC=Climate Change

resulting in very significant increases in erosion (plus 155.1 percent). Inversely, the 2080 modeled scenario for CC1 indicates a slight increase in erosion (plus 5.3 percent) that could be more than offset by proactive land use policies and governance, reducing overall erosion by up to 32.5 percent. At all time scales, land use scenarios induce more variability in erosion than do the climate change scenarios.

6.2.2 Measures to address constraints

The national water utility (SANAA) and the Honduran Ministry of Forests and Conservation (ICF) have developed a watershed management plan for the Guacerique watershed with the overall objective of ensuring long-term water availability and lowering sediment loads in the Guacerique River in order to maximize the watershed's utility as a source of drinking water for Tegucigalpa.[18]

18. See SANAA and ICF (2011). As mandated by the Law on Forests, Protected Areas and Wildlife, forest-related management plans, including watershed management plans, are officially the responsibility of ICF. However, the watershed management plan for the Guacerique watershed has been a collaborative effort between SANAA and ICF, and responsibility for implementation has been primarily delegated to SANAA.

The watershed management plan has both environmental and poverty alleviation objectives. It aims to clearly map out land ownership, develop an integrated natural resource management program focused on water and forest resources, build economic and management capacity within local communities, monitor environmental indicators, and undertake disaster risk management (SANAA and ICF 2011). The water managers understand that broader environmental goals will only be achieved through collaboration with the watershed's inhabitants, especially upstream inhabitants, whose needs and aspirations must be met.

The watershed management plan contains the following specific forest- and soil-related activities that are of particular interest to this study:

- Reforest 1,236 ha around springs and creeks
- Create 100 ha of fuelwood plantations
- Transition to agroforestry on 161 ha of steeply sloping agricultural land (on slopes of 30 percent or more)

- Concentrate forest fire control on reforested areas
- Reduce illegal timber extraction on 6,063 ha classified as forest reserve
- Concentrate pest control on 4,338 ha of existing pine forests
- Implement soil conservation measures on 2,000 ha of agricultural fields

This is a six-year plan that received ministerial approval in the last quarter of 2012. SANAA will be in charge of implementation. Community engagement constitutes SANAA's principal approach to implementation, as the utility recognizes that success depends on the communities' acceptance and support of the plan and its activities. In accordance with the Law on Forests, Protected Areas and Wildlife, Guacerique watershed residents will also participate in implementation through a recently elected watershed council. Water managers hope to be able to engage communities through payment for environmental services mechanisms that provide communities with resources for grassroots conservation efforts.

The watershed management plan adds to the many infrastructure projects developed over the years to address water shortages, including the construction of new reservoirs (such as Guacerique II, Rio del Hombre 6 and 7, and Ojojona) and improvements or connections to existing reservoirs (such as Tatumbla, Sabacuante, Nacaome, and Jinguare) (CETI S.A. 2011). Multiple studies have identified the Guacerique II reservoir, sited upstream from the Los Laureles reservoir in the Guacerique watershed, as the most viable project (CETI S.A. 2011; SOGREAH Consultants 2004).

Financing has yet to be secured for any of these watershed management or infrastructural projects. It is very likely that SANAA will rely on alternate funding sources, primarily development aid, to fund implementation.[19]

6.2.3 Economic case for forests

The economic analysis quantifies the potential benefits derived from the implementation of the Guacerique watershed management plan, particularly the impacts on key ES and the resulting cost savings through time to the national water utility, which has important drinking water infrastructure in the watershed. The study calculated benefits to 2035, providing a 20-year time horizon. The analysis focused on two specific ES: water yield and erosion regulation (this latter ecosystem service because of its direct relationship with water quality). The study also explored the extent and type of additional benefits that could accrue to various actors from these EBA measures.

EXPERT JUDGMENT

Expert judgment of the future performance of the four variables related to drinking water infrastructure with the successful implementation of the watershed management plan u*nder the low climate change scenario* indicates that:

- Sedimentation in the reservoir will decrease by 18.0 percent;
- Turbidity in the reservoir will decrease by 24.0 percent;
- Dissolved oxygen levels during the annual dry period will increase by 7.0 percent;
- Water inflow into the reservoir during the annual dry period will increase by 11.3 percent.

19. Currently, the Adaptation Fund project has some funds earmarked for reforestation activities, environmental protection training, and management capacity building in the Guacerique watershed. Further funds will be sought now that the plan has become law.

TABLE 3. ANNUAL BENEFITS GENERATED BY THE WATERSHED MANAGEMENT PLAN, 2030–35 (UNDISCOUNTED 2012 DOLLARS)

	Low climate change scenario	High climate change scenario
Storage volume	$929	–$671
Additional water	$3,575,830	$9,176,908
Water quality	$129,447	–$24,448
Totals *(rounded)*	**$3,706,000**	**$9,152,000**

Expert judgment of the future performance of the four variables related to drinking water infrastructure with the successful implementation of the watershed management plan under the high climate change scenario indicates that:

- Sedimentation in the reservoir will increase by 13.0 percent;
- Turbidity in the reservoir will increase by 9.8 percent;
- Dissolved oxygen levels during the annual dry period will increase by 23.8 percent;
- Water inflow into the reservoir during the annual dry period will increase by 29.0 percent.

ANNUAL AND NET ECONOMIC BENEFITS

The overall annual economic benefit of the watershed management plan to the national water utility for the years 2030–35 expressed in undiscounted 2012 dollars is about $3.7 million under the low climate change scenario and about $9.2 million under the high climate change scenario. Table 3 summarizes the values for each variable and the sum for each climate change scenario.

The net economic benefit expected to accrue from the watershed management plan ranges from $23.6 million to $34.7 million for the low climate change scenario and from $63.6 million to $91.5 million for the high climate change scenario, depending on the social discount rate applied (our scenarios used 2.1, 3.3, and 4.5 percent). Assuming a moderate economic growth rate in the future, the net economic benefit of the watershed management plan is approximately $28.6 million under the low climate change scenario and $76.1 million under the high climate change scenario. Our calculations assume that 60 percent of total benefits materialize in 2019 and that benefit provision increases in a linear fashion, reaching 100 percent in 2030 and remaining at this level through 2035.

6.2.4 Institutional changes needed

It is clear that the overarching legal framework has many elements that encourage forest-based climate change adaptation. Climate change is firmly on the national agenda through the climate change strategy and the National Development Plan, which support future legislative activities for stronger institutional decision making on climate change. Moreover, the legislation emphasizes the role of forests in environmental health and social well-being, and it includes important mechanisms for achieving conservation goals, including provisions for PES programs and multistakeholder involvement.

But a lack of resources, political will, and clear mandates, along with barriers to broad-based community participation, among other problems, mean that rule enforcement remains a challenge.

Nonetheless, key aspects of the existing legislation are being put into practice, like the development and implementation of watershed management plans. Lessons learned from the development of the Guacerique watershed management plan are now being applied to the management plans of other watersheds that produce drinking water for Tegucigalpa.

Our analysis found that the institution that manages the water supply infrastructure has low adaptive capacity, although it is important to point out that many—if not most—institutions find themselves in this position. At the same time, the institution has shown some resilience in the face of the impacts of climate extremes experienced in the recent past. Communities are also judged to have low adaptive capacity due primarily to the rates of poverty, lack of education, and the resource-poor municipal government. Nonetheless, communities demonstrate resilience in everyday solutions to household needs and changing conditions; community capacity to adapt should not be underestimated. Finally, there are additional barriers, ranging from funding constraints to challenges of evaluating management options given future climate uncertainties.

We sought feedback from stakeholders on alternative governance approaches for successful EBA in the Guacerique watershed. They identified multiple pathways for resolving water resource management issues by using the means-ends objective approach. This approach has been used in the past to characterize components of governance mechanisms for ES conservation (Vignola, McDaniels, and Scholz 2012). Using this approach, stakeholders identified a set of basic requirements for improving water and forest resource governance that would help reduce sensitivity to climate change and improve adaptive capacity. The actions are grouped into five categories: resource generation, government mandates, planning and learning, interinstitutional coordination, and implementation.

With regard to financial resource generation, stakeholders highlight the need for more resources for conservation in general and see payment for environmental services (PES) schemes as one of the most promising areas for resource generation for watershed management and water conservation initiatives.

With regard to government mandates, stakeholders state that above all it is important to generate the political will among decision makers and government representatives. Beyond that, it is also important to address gaps in legislation and to clearly define the roles and responsibilities for each stakeholder or stakeholder group. This is a critical precondition allowing for various parties to effectively collaborate and coordinate activities.

When it comes to planning and learning, stakeholders suggest that activities and intervention sites be prioritized and that programs be accompanied by a strong monitoring component.

Actions to facilitate interinstitutional coordination respond to stakeholders' recognition that it is important to carry out activities at multiple scales—from the river basin down through the watershed, municipality, and community. Research shows that controlling land use change is the most important factor in achieving watershed management goals and that building effective relationships with municipal governments and encouraging municipal exercise of land use planning mandates are essential. Furthermore, it is important to generate consensus between stakeholders on the objectives of any particular plan, policy, program, or initiative so that stakeholders agree on the problem and become empowered to act in ways that contribute to achieving collectively set goals.

With regard to implementation, stakeholders feel that providing communities with training and financial resources is an effective way to increase community participation in watershed management efforts. Also, in this particular case, stakeholders see agricultural extension as key to improving land use and forest conservation, with important spin-offs for household well-being, including improved incomes and local and regional food security.

6.3 Lao PDR—Forests and agriculture

Lao PDR has approximately 9.5 million ha of forest cover, which constitutes 40 percent of the total land area. Some 73 percent of the nation's population lives in rural areas (NSC 2006). The country experienced steady economic growth of 6.5 percent per year on average between 1990 and 2009 despite the regional and global financial crisis. This was largely due to the demand for resources from its neighbors—China, Thailand, and Vietnam—and from the foreign direct investment (FDI) inflows over the past decade. The government's Seventh National Socio-Economic Development Plan for 2011–2015 specifies the intention to attract significant FDI and to increase forest cover from 40 percent in 2010 to 70 percent by 2020. These developments have had positive impacts on poverty reduction in Lao PDR: the share of poverty was reduced by 30 percent in one decade, lifting one-eighth of the total population out of poverty. Despite the positive achievements, the poverty rate in Lao PDR remains higher than in neighboring countries. Furthermore, the risks of relying on unsustainable resource management practices include increased environmental degradation and inequality.

In 2012, an estimated 5 million ha of Lao PDR was leased or conceded to domestic and foreign investors. The bulk of these areas are for mining concessions (primarily exploratory). The second largest type of investment is agricultural investments.[20] The southern provinces of Lao PDR have large areas available for leasing and concession. Some of the provinces in that region are home to the unique ecosystem of Dry Dipterocarp Forests (DDF), which are important savanna-like forests. In Lao PDR, DDF represent 13 percent of the total forest estate, as well as a unique vegetative ecotype spanning parts of Southeast Asia, including endangered flora and fauna. These systems are increasingly targeted for conversion to commercial plantations. DDF systems, however, provide local stakeholders with a range of ES—most important, they provide fodder for livestock and other NTFPs for consumption and sale, both of which reduce households' sensitivity to climate change and strengthen their adaptive capacity. DDF also support rice production by regulating hydrological flows and limiting erosion. National policy makers indicate a need for better data to inform decision makers involved in balancing the needs of local rural livelihoods with national development priorities aimed at attracting foreign investment.

The case study covers three villages in Savannakhet Province:

- A PSFM village (Sustainable Forest Management through Rural Development), where no concessions occurred and where communal forestland covers 3.74 ha per person
- A eucalyptus village, where 45 percent of village forestland was converted to eucalyptus plantations and the remaining communal forest covers 0.73 ha per person

20. www.forestcarbonasia.org/wp-content/uploads/2012/02/Legal_Framework_of_Concessions_in_the_Lao_PDR_-_Discussion_paper.pdf

- A sugarcane village, where 75 percent of village forestland was converted to sugarcane plantations and where there is no remaining communal forest.

The aim is to explore how forests, through the provision of ES, contribute to the adaptation of smallholder agriculture households in the DDF region. The methodology combines secondary data collection with national, provincial, and district stakeholder consultations; with village stakeholder participatory rural appraisals; and with an illustrative survey sampling of households about household demographics, sources of income, expenditures, and food self-sufficiency. It compares households with access to forests with households in areas with conversion of forests to large-scale eucalyptus and sugarcane concessions.

6.3.1 Agriculture

Seventy-three percent of the Lao PDR's population lives in rural areas (NSC 2006). The main staple crop contributing to national food security is glutinous rice. In some parts of the country, more than 80 percent of the households rely on rainwater for rice cultivation. Even low-intensity natural disasters can increase the vulnerability of rural farmers because of the high degree of poverty in these areas. It is expected that increased climate variability might threaten agricultural production (in particular, rice), affecting the economy of the country and food security (World Bank 2011).

Forests provide regulatory services, such as absorption and regulation of water flows as well as the prevention of erosion in areas with shallow, often sandy soils that underpin agricultural livelihood activities. Though difficult to quantify in terms of their economic contribution, these services are widely recognized by Lao farmers as important to rice production (see also Fujita 2000).

In addition to their direct impacts on agricultural production, the DDF in Lao PDR make significant contributions to household food security by providing products for direct consumption as well as a regular income from products sold for cash. Without the contributions of forests, rural small-scale agricultural households in the DDF areas of Lao PDR would struggle to maintain their agricultural livelihood strategies altogether.

Sustainable agriculture and forest resource management are also recognized as important when considering the gross domestic product figures for 2008–10, where the sectors together contributed 30 percent. Meanwhile, they also provided 75 percent of total employment.

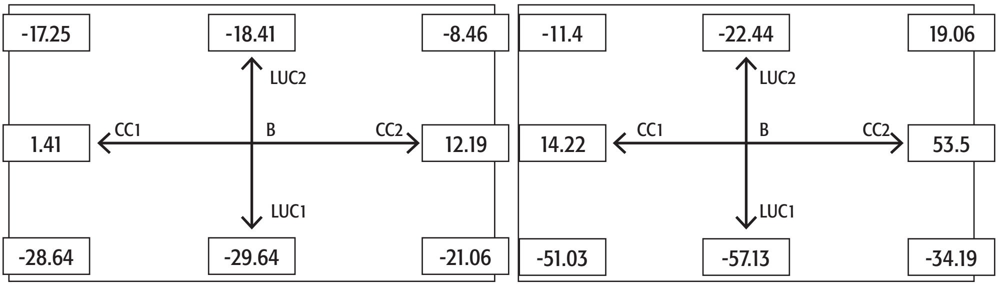
6.3.2 Climate change and land use impacts

IMPACTS OF CLIMATE CHANGE ON ES

Due to relatively stable precipitation and rising mean temperatures, all climate change scenarios project an increase in net primary productivity (vegetation growth) in Savannakhet Province. It should be noted that the proportional impact on the growth of rice in paddies is likely to be more significant than that of DDF forests, however, as growth in the latter is primarily limited by soil depth. The expected impact on paddy field rice production is a net increase in primary productivity of 1.4–12.2 percent by 2030 and 14–53 percent by 2080. These findings are consistent with other studies (Lefroy, Collet, and Grovermann 2010; Jintraet and Chinvanno 2012).

Looking at seasonal rainfall patterns in the longer term, climate change scenario projections indicate significant uncertainty regarding the amount of rainfall and runoff during the month of June. This is a critical period in the agricultural production calendar, when farmers transfer rice plants from nurseries to paddies, and when

FIGURE 7. EXTREME SCENARIOS OF IMPACTS ON NPP FORESTS IN LAO PDR FOR CLIMATE AND LAND USE CHANGE PROJECTIONS (2030, 2080)



Change in NPP compared with the baseline (B) for two contrasting climate scenarios (CC1 - HAD3.B2A and CC2 - CSIRO2.B1A in 2030; CC1 - CGCM2.A2A and CC2 - CSIRO.A1A in 2080) and two contrasting land use change scenarios (LUC1 - IMAGE.B2 and LUC2 - IMAGE.B1 in 2030 (left) and LUC1 - IMAGE.A2 and LUC2 - IMAGE.B1 in 2080 (right)) in areas with natural vegetation

Notes: LUC=Land Use Change; CC=Climate Change

predictability of water levels is particularly important. Crop failure is a risk whenever there are major interruptions in rainfall or there is sudden overabundance.

Based on modeling Holdridge life zones, the overall increase in temperatures is likely to contribute to a general qualitative shift in vegetative composition toward plant species more adapted to drier conditions. This should not, however, be confused with a transition toward DDF, as DDF trees are more accurately characteristic of specific soil conditions than they are of temperature per se.

IMPACTS OF LAND USE CHANGE ON ES

Using IMAGE 2.2, we found that policy and economic drivers of land use change are likely to significantly outweigh any impacts from climate change on forest productivity. When climate and land use scenarios are combined, due to projections of land use change in this region, forest production is expected to decrease by 2030 under every scenario modeled (with declines ranging between 8 and 30 percent) (see Figure 7). This would correspond with the strong perception among Lao stakeholders at all levels that land use change is the key challenge to be addressed in terms of deforestation and degradation of DDFs.

There does appear to be an inflection point toward the middle of the century, when policies regulating long-term drivers of land use change may combine with climate change to yield either a net positive or negative outcome for NPP (between plus 19.06 percent and minus 51.03 percent) compared with the recent baseline level. Overall, the message would seem to be that while climate change may improve average rice production, policy makers cannot expect the same easy wins with regard to forest conservation, as policy and economic drivers have to be addressed in order for any climatic drivers of growth to be felt.

6.3.3 Forest-enabled household resilience strategy

The total annual value of subsistence use and commercial use of NTFPs in the whole country was estimated in 2010 to be $510 million per year, 9.7 percent of the gross domestic product (Foppes and Samontry 2010). In addition to these direct benefits, forest ecosystems support smallholder agricultural and livestock production systems. The main staple crop, glutinous rice, is produced predominantly in rainfed paddy fields. Farmers perceive rice production to depend largely on the capacity of forests to absorb and regulate flows of water (Fujita 2000). Similarly, the significant number of large livestock (buffaloes and cows) kept by smallholder farmers depend mainly on natural grass vegetation in forestlands, as the country has only limited pasturelands (Zola and Frazer 2012).

Across all three communities, forest resources constitute an average of 35 percent of annual total income. The communities with less forest relied to a greater extent on income from wage labor (8 percent in the PSFM village versus 29–33 percent in the villages with concessions) and on remittances from migration (1 percent in the PSFM village versus 5–13 percent in the villages with concessions), and they had reduced livestock holdings. Due to limited demand for labor in sugarcane and eucalyptus concessions, the majority of labor income comes from outside the village.

In the PSFM village, forest resources are the primary source of cash income across wealth categories, through NTFPs (55 percent) and livestock sales (26 percent). The most important NTFPs were mushrooms (10 percent), frogs and snails (16 percent), insects (10 percent), and bamboo and rattan (7 percent). DDF provisioning services were valued at $54 per ha per year. Non-cash income in this village represented 68 percent of total income. In the other communities, non-cash income represented 35–41 percent of total income.

Total average household incomes in the villages look similar ($1,514–1,736 per year); however, it should be underscored that this represents a significant decrease in food self-sufficiency, as it costs more to replace gathered wild products with cultivated products. Further, in most cases households in concession villages indicated that they do not purchase equivalent amounts or the same diversity of plant or protein to that lost with disappearance of the forest.

The value of livestock owned by households was equivalent to 3.6 years of average annual household cash income in the PSFM village, compared with 1.2 years in the eucalyptus village and 1.0 years in the sugarcane village. This illustrates the key role of livestock as a source of savings and/or a safety mechanism during times of crisis.

Villagers estimated that their large livestock depend on natural stands of Arundinaria grass in DDFs for 80 percent of their grazing requirement. Fodder from forests therefore represents a significant source of resilience to shocks—a resource that is lost when DDF is converted to concessions. Elevated livestock sales in the eucalyptus village may reflect the loss of forest grazing land.

Local communities have used a number of strategies to cope with land use change, some of which may also be applied to climate change. However, most of these strategies result in a deterioration rather than improvement in overall livelihood conditions:

- Privatization of remaining communal land (claimed at conversion to paddy land)
- Working harder as hired labor to earn money to buy food, reducing ability to produce food

- Migration of young people (mostly girls) to Thailand, exposing them to risks of human trafficking
- Seeking arbitration in conflicts with companies to obtain compensation for land lost to concessions, although incompatibilities between policies and lack of formal adjudication mechanisms makes this challenging

6.3.4 Economic valuation of forests versus concessions

Findings from the Lao PDR case study demonstrate that ecosystem services provide an immediate and measurable source of annual returns to households through sale and/or replacement values for livestock, NTFPs, firewood, construction materials, and domestic water supplies. The value of the current estimated annual income in the PSFM village from these provisioning services is $20.66 per ha (see Table 4). In addition, after adding a conservative estimation of the contributions of DDF to the regulation of the water supplies and erosion control for agricultural production, the total value of known, quantifiable ecosystem services is estimated at $46.97 per ha. Table 4 also indicates some option values, or co-benefits, arising from conservation of the resource (potential for sustainable off-take on the basis of a 110-year rotation and the value of the standing carbon on the global carbon credit trading market).

Three of these ecosystem services can be regarded as "assets" that communities may use and sell or trade in times of emergency. As such, the DDF ecosystem provides an important safety net. The total of DDF ecosystem asset sale value in the PSFM village amounts to $1,215 per ha (see Table 5).

TABLE 4: ECONOMIC VALUES OF DRY FOREST ECOSYSTEM SERVICES AS ANNUAL RETURNS TO THE PSFM VILLAGE

Dry Forest Ecosystem Services Annual Returns	Kip/ha	Dollars/ha
Livestock sales	88,214	$ 11.0
NTFP sales and consumption	33,510	$ 4.2
Timber for house construction	24,000	$ 3.0
Firewood consumption	8,706	$ 1.1
Domestic water use	10,857	$ 1.4
Total value provisioning services	**165,288**	**$ 20.7**
Erosion control (25 percent of rice production)	210,455	$ 26.31
Total value regulatory services	**210,455**	**$ 26.31**
Actual contribution to household income	**375,743**	**$ 46.97**
Potential from timber sales (110 -yr cycle)	55,273	$ 6.91
Potential annual carbon value	28,435	$ 3.55
Total option values	**83,708**	**$ 10.46**
Overall potential value	**459,451**	**$ 57.43**

TABLE 5: THE VALUE OF DRY FOREST ECOSYSTEM SERVICES AS LIVELIHOOD ASSETS IN THE PSFM VILLAGE

Dry Forest Ecosystem Services as Assets	Kip/ha	Dollar/ ha
Timber	6,080,000	$ 760
Carbon assets	3,127,897	$ 391
Livestock assets	508.812	$ 64
Total ecosystem assets value	9,716,709	$ 1,215

The limited data available regarding the productivity of eucalyptus and sugarcane plantations on DDF soils suggest these to be potentially risky investments, in both the short term and the long term. Anecdotal evidence suggests that the average future production levels in these plantations may result in a net loss on investments. It must also be underscored that any measure of economic viability should include the costs of meaningful compensation to local communities for DDF ecosystem services lost. In the event of any unviable concession developments on DDF soils, it is important to note that the impacts on livelihoods and ecosystem services may well be irreversible. This is because the shallow soils, once eroded, are gone and because most DDF tree species take over 100 years to reach harvestable size.

It should also be noted that future expansion of the area under rice cultivation through the conversion of individually owned plots of DDF forest is likely to be of limited value in reducing vulnerability. While climate change may be expected to raise the productivity of existing paddy fields, the success rate of these new conversions is likely to be limited, as these are mostly located on the top of ridges in the topography, where soils are very shallow and prone to droughts. The greatest economic benefit is likely to be gained from enhancing production levels in existing paddies and protecting the DDFs to ensure provision of NTFPs, timber, and livestock grazing fodder.

6.3.5 Institutional changes needed

DDF land is increasingly targeted for conversion to commercial plantations, where large tracts of land are being allocated to foreign companies. This forms part of the Lao PDR government's attempt to leverage its land resources to attract foreign investment. Unfortunately it would appear that the concessions being granted provide very limited benefits for rural stakeholders, while undermining their livelihoods and resilience to shocks. National policy makers need to put in place mechanisms that better balance the needs of local livelihoods with national development priorities.

More effort is needed to improve land use planning, especially with respect to incorporating the values of forest ES in all decision-making systems around conversion of forestland. Currently, the allocation of concessions often results in the loss of benefits to local stakeholders, especially poor smallholder agriculture and forest-dependent communities. National partners could explore several ways to include measurable values into land use planning processes:

- How many hectares of paddy land should be allocated per household or per person to ensure future food self-sufficiency?
- How many hectares of DDF forest should be preserved per household or per person to allow a minimum resilience buffer to shocks?

- What criteria could be applied to ensure that companies can demonstrate the viability of concessions, compared with existing ecosystem values, before they are granted?
- Where concessions are allocated land that is in use by communities, what amount and form of compensation would help the communities replace the lost forest benefits?
- What local institutional monitoring and arbitration/adjudication mechanisms are needed to safeguard the interests of local stakeholders and the state?

Stronger mediation and conflict resolution support is needed. There are numerous documented cases of conflicts between local stakeholders and concessions due to a combination of a lack of adequate rural land titling, poor stakeholder engagement and documentation by concession holders, and an absence of conflict resolution platforms. In the communities associated with concessions in this study, most of the remaining, formerly communal forests are undergoing privatization by individual households as a direct response to the fear of additional land being lost to concessions. Any such subdivision results in a net loss of benefits to all.

A considerable share of the total area under investment in Lao PDR (approximately 29 percent of the total area) and number of projects (26 percent of the total number of investment projects) occur on land categorized as forest, although there is a national regulation that discourages land investment in forestry. There are forest areas that can be considered for investments in agricultural commodities. It is important to ensure that DDF is not considered degraded or barren forestland.

More effective enforcement of rules on forest protection is essential. Notably, illegal logging cannot be stopped by law enforcement alone. Villagers need incentives to contribute to law enforcement, such as through payment for patrolling, fire management, reforestation, and other ecosystem management services.

7 CONCLUSIONS AND RECOMMENDATIONS

Forests generate provisioning, regulatory, and supporting services that can enhance the resilience of social and economic systems in other sectors. Existing evidence and the case studies that are the basis of this report reveal that forests offer economic assets that can help reduce sensitivity and strengthen adaptive capacity through the supply of wood and wood products such as fuelwood, paper, charcoal and wood structural products, and non-wood products (foods and plant products) such as rattan, mushrooms, nuts and fruits, honey, bushmeat, rubber, and biological compounds used for medicines (Louman et al. 2009). Additional services from forests are not readily monetized. They include habitat provision, clean water, flood protection, carbon sequestration[21] and storage, climate regulation, oxygen production, nutrient cycling, genetic resources for crops, and spiritual, cultural, recreational values (Louman et al. 2009).

Forests' services and goods can augment the resilience of systems in other sectors. Managing forests for these benefits will require specific institutional measures and management practices that account for the potential impact of climate change on forests. Forests can contribute most effectively to resilience when blended with other built infrastructure measures. Adding forests, as a form of ecosystem-based adaptation, to the built infrastructure measures could generate medium- and long-term ecosystem benefits in addition to strengthening the adaptation measures.

Optimizing the use of forests for resilience can help buffer households with limited access to alternative risk-mitigating instruments or systems from climate change-related shocks and chronic changes. Management of forests as part of a broader adaptation strategy can often be a low-cost measure if necessary institutional requirements are in place. Implementing the institutional requirements can raise the financial cost of using forests for adaptation. However, the social and environmental co-benefits, including mitigation benefits (the broader economic benefits) that result from the use of forests, justify the investment in the institutional measures. Several considerations justify and facilitate the use of forests for adaptation; some key considerations are described briefly in this section.

21. It should be noted that the CO_2 sequestration capacity decreases as forests are affected by changes in temperature and precipitation and the rate of growth declines. Recent evidence (Stephenson et al. 2014) suggests that individual trees keep growing as they age, continuing to sequester carbon. However, the number of large old trees decreases in a stand, so the overall stand-level sequestration may change over time.

7.1 Linkage between land use change and climate change: Justifying the use of forests

When examining the impact of climate change in the next 20–50 years, the linkages between climate change and land use change are very evident. Land use change resulting from allocation of concessions, illegal resource use, and unsustainable resource management interact with the consequences of climate change and often reduce the potential positive impacts or compound predicted negative impacts. Evidence from climate change and land use modeling on three key parameters—net primary productivity, runoff, and fire fraction—in the three country case studies shows how land use change can reduce possible gains in NPP, as was the case in Lao PDR and for most of the scenarios considered in Burkina Faso.

The interlinkages between land use change and climate change suggest that sustainable management of forests and trees—management that is ecologically, economically, and socially sustainable—can enable the positive medium-term outcomes of climate change, such as increased net primary productivity or reduced erosivity. Independent of these outcomes, sustainable management of forests to generate provisioning goods can also reduce the sensitivity of a system and augment adaptive capacity, as evidenced in Lao PDR.

For countries with similar contexts to the three case studies, giving priority to addressing land use change can service the adaptation needs of sectors that are closely linked to natural resources (such as energy, water, and agriculture). In these cases, the value of the forests' ecosystem services should be internalized in order to reduce unsustainable land conversion and maintain resilient landscapes, which can be central to a robust adaptation strategy. Furthermore, forest conversions may represent "maladaptations" to climate change where the investment is high-risk, the local benefits are limited, and/or the consequences irreversible.

Large-scale forest conversions can limit the adaptation options for both rural stakeholders and national decision makers in the future. In Lao PDR, there are numerous examples of conflicts between concessions and dispossessed communities in areas where DDF are converted for plantations or production of agricultural commodities. Such forest conversions must be recognized as relatively irreversible due to slow forest regeneration on shallow DDF soils (roughly 100 years to grow to a size where trees become commercially valuable). Evidence from a modest sample of households also reveals that, while households living near concessions make more income, the income generated does not compensate for the value of 'adaptation services' lost to forest conversion. In the case of the Honduras study, the failure of policy makers to fully fund and implement the watershed management plan would represent a de facto maladaptation choice.

7.2 Additional research on optimizing forest use as part of a larger adaptation strategy

The use of forests to reduce vulnerability to climate change is likely to be optimized when done in combination with other adaptation measures. For example, the use of mangrove forests as coastal defense against severe weather events is often most effective when combined with dikes and breakwaters. Growing acceptance of this approach has resulted in what is known as "hybrid engineering," which combines engineering techniques with natural processes and resources. The aim is to create dynamic solutions that are able to adapt to changing circumstances and generate the co-benefits associated with an EBA (Wetlands International n.d.). In the case of Honduras, the watershed management plan is "not enough" under more-extreme climate change scenarios, and a combination of watershed, infrastructure, and institutional development plans will need to be implemented. Should precipitation increase over the next 20 years, the water utility can expect to continue to experience problems with sedimentation and turbidity at levels that improved watershed management cannot fully mitigate.

Understanding the appropriate balance between EBA and infrastructure-based adaptation measures can require additional research. This is the case for Honduras, where, under the low climate change scenario, the performance of the four variables (sedimentation, turbidity, dissolved oxygen, and water inflow) related to drinking water infrastructure is expected to greatly improve with implementation of the watershed management plan. However, significant increases in precipitation could override any gains in erosion regulation. Under the high climate change scenarios, the watershed management plan is expected to contribute to resolving issues with dissolved oxygen levels (eutrophication during the dry season), especially where increased precipitation is combined with decreased sedimentation. Under both the low and high climate change scenarios, the plan is expected to increase the amount of water entering the reservoir during the annual dry season. Afforestation is expected to increase base flow (by increasing infiltration), despite the marked decrease in precipitation under the low climate change scenario, with even better outcomes projected under the high climate change scenario, given the increase in precipitation. However, work by Locatelli and Vignola (2009) demonstrates that the effect of deforestation and afforestation on stream flow is not uniform.

To identify the optimal combination between EBA and infrastructure-based adaptation measures, it is also important to improve our understanding of the regulatory and supporting services of forests. Currently a common assumption is that these services are spread uniformly across a landscape. Accordingly, most analysis works with the average benefit rather than the marginal benefit of increasing the area under EBA by a unit. Comprehending the marginal benefits of EBA in turn requires additional research on several relevant dimensions, including the impact of climate change on the ecological and agricultural systems found in developing countries, the consequence of extreme events on ecological systems, and further refinement of the Holdridge life zones.

7.3 The economic case for using forests to improve resilience

Existing studies and evidence from the three country case studies reveal that the financial analysis does not always favor adaptation of forests or improving resilience to climate change. When economic benefits and the importance of ensuring equitable access to adaptation services are accounted for, the case for EBA approaches is more compelling. Obtaining the necessary financial and economic evidence for using forests to improve resilience is challenging. In Burkina Faso, for example, while the cost of more of an EBA approach involving modernizing the wood energy value chain could be estimated, it was difficult to obtain the associated costs for an alternative approach—the expansion of the use of LPG.

The economic case for using forests to improve resilience often involves some financial analysis combined with expert opinion. The approaches adopted in Honduras and Burkina Faso offer two ways of blending quantitative information with expert opinion. In Honduras, expert opinion was important to augment information available on the performance of a set of variables related to the drinking water infrastructure and general ecosystem service provision within the watershed. (The services were related to reservoir sedimentation rates, turbidity levels in the reservoir, dissolved oxygen levels in the reservoir during the annual dry season, and the amount of water entering the reservoir during the dry season.) Experts offered their judgments on the performance of these variables in the year 2030, assuming successful implementation of the watershed management plan, under the low and high climate change scenarios. In Burkina Faso, expert opinion helped determine which of the proposed measures would reduce sensitivity and improve adaptive capacity—and how.

Making a robust economic case for using forests to enhance resilience will require comparing the use of forests with other options. Accordingly, drawing on approaches used in the valuation of regulatory and supporting services of ecosystems and identifying the full cost of alternative approaches will be important. One element in favor of EBA approaches is that they often involve no-regret measures, the implementation of which are made more urgent by climate change.

7.4 Institutional dimensions and potential opportunities for implementing EBA

Use of forests to enhance resilience will **require government agencies and authorities to work more closely with communities in building a shared vision for landscapes and livelihoods**. In Honduras, SANAA's ability to implement the watershed management plan and work with other stakeholders (like municipal governments) to control land use change in the watershed may be limited by the level of legitimacy that these stakeholders attribute to SANAA and their willingness to work with the utility on these goals. Rectifying this situation and improving the level of community engagement will be fundamental to motivate support for implementation of the EBA approach. Similarly, in Burkina Faso, decentralization of the wood value chain will require building relationships with the local authorities and stakeholders in the value chain to obtain their commitment to and ownership of any proposed changes.

Better coordination among authorities is essential to effectively implement EBA, including clarification of roles and responsibilities and improvements in reporting mechanisms. In Honduras, the achievement of land and resource management goals in the watershed requires coordination across various institutions, including at a minimum two municipalities and two or more departments of the water utility and the Ministry of Forests and Conservation. Mutual recognition of legitimacy and authority, strong relationships and consensus on adaptation (land management) objectives, and communication or coordination mechanisms are required for objectives to be achieved. In Lao PDR, different levels of government have the right to sign concession agreements, depending on their scale. In effect, these levels of government compete with each other for revenue from concession holders, and consequently they have little incentive to communicate or show transparency regarding concessions (Barney and Canby 2011; Schoenweger and Uellenberg 2009; Schumann et al. 2006). Barney and Canby (2011) also emphasize the challenge of enforcing accountability of government institutions when conflicts exist between regulations, guidelines, and decrees.

To support the use of forests to enhance resilience to climate change in the three country case studies, it is necessary to **support farmers' adoption of sustainable agriculture and forest management practices**. In Burkina Faso, participatory natural resource management will be instrumental for using forests as an EBA measure. This will involve supporting sustainable management of natural forests, identifying priority natural forests for participatory management and the production of wood energy, facilitating the development of simple management tools, assisting the establishment of organizations and facilitating the transfer of skills in managing forest resources to local authorities and management structures, extending the forest plantation area for energy purposes, and promoting and strengthening agroforestry. Similarly, farmers in the Guacerique watershed in Honduras will likely have to adjust to drier growing conditions and more-erratic rainfall patterns. In order for subsistence farmers to participate in forest conservation and reforestation activities, they need to perceive the direct benefit for their livelihoods. The adoption of forest and agricultural soil conservation practices by farmers is closely linked to the availability of technical assistance (Vignola, McDaniels, and Scholz 2010). Overall benefits to the water utility increase the sooner that effective soil erosion prevention measures are in place, providing additional incentive for giving priority to the adoption of soil and forest conservation practices.

Successful EBA implementation requires a **financial commitment by government and partner institutions.** In the Honduras case study, lack of funding currently puts plan implementation at risk and means that land management goals may not be achieved. Despite the fact that the water utility has explicitly espoused watershed management as a resource management strategy, the watershed management unit receives limited funding. This reduces its ability to contribute effectively to both infrastructure and environmental management goals. Thus it is paramount to identify suitable funding mechanisms to pave the way for the effective implementation of the Guacerique and other watershed management plans. In Burkina Faso, financing will need to be obtained from a range of sources, including public sources (such as the state budget and budgets of the local authorities), various funds (for example, the Forestry Development Fund), and private contributions (such as communities, the private sector, and NGOs). In addition, it will be essential to have a feasible mechanism for pooling these funds and using them for the intended purpose.

Ecosystem-based adaptation measures need to be adaptive. Accordingly, monitoring systems are vital to inform the development and adjustment of EBA responses. Forest management approaches that halt or reverse deforestation can have a positive impact on soil erosion rates, as demonstrated in the Honduras study. However, planning and implementing EBA measures is characterized by large uncertainties in terms of both the impacts of climate change on ecosystems and the effectiveness of certain erosion reduction practices. To optimize resources, it is important to generate information, through monitoring, to allow managers to adjust measures through time. Monitoring should provide information on changes in key areas and variables including climate change, track progress on the adoption of forest and soil conservation measures, and measure comparative success in reducing erosion and promoting water infiltration. With respect to monitoring climate change, this may require countries to invest in Hydromet systems and also in building capacity on how to better understand and explain the management options proposed. Such investments would help use data to inform decisions.

To enable the use of forests for an EBA approach, it will be imperative to **refine, strengthen, and enforce plans and regulations in line with managing for climate change and variability projections, with particular consideration of forest conversion**. In Honduras, it may be that SANAA's ability to manage forest and water resources in the watershed under a changing climate is inhibited by existing laws and regulations that define "suitable" management practices in a conservation area and by other institutional practices that entrench ways of doing things or inhibit managers from making certain decisions. Forest and water managers should also expect changes in the predominant forest ecosystem in the watershed, which presents a management challenge in understanding how to intervene most appropriately on a landscape undergoing natural processes of change and what impact these processes will have on the provision of a wide range of ES. In Lao PDR, more effective enforcement of rules on forest protection is essential, especially to counter illegal logging. While moratoria on logging and concessions have been imposed by government from time to time, the rate of land conversion and forest cover loss has not been altered significantly (Barney and Canby 2011; Dwyer 2011; Kenney-Lazar 2010; Schoenweger and Uellenberg 2009). Villagers may also need incentives to contribute to law enforcement, for instance through payments for patrolling, fire management, reforestation, and other ecosystem management services.

8 REFERENCES

ADB (Asian Development Bank). 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review*. Asian Development Bank.

Adger, W. N., N. W. Arnell, and E. L. Tompkins. 2005. "Adapting to Climate Change: Perspectives Across Scales." *Global Environmental Change* 15: 75–76.

Adler, C. E., D. McEvoy, P. Chhetri, and E. Kruk. 2013. "The Role of Tourism in Changing Climate for Conservation and Development. A Problem-Oriented Study in the Kailas Sacred Landscape, Nepal." *Policy Sciences* 46(2): 161–78.

Aguilar, E., T. C. Peterson, P. Ramýrez Obando, R. Frutos, J. A. Retana, M. Solera, J. Soley et al. 2005. "Changes in Precipitation and Temperature Extremes in Central America and Northern South America, 1961–2003." *Journal of Geophysical Research* 110: D23107.

Alo, C. A., and G. Wang. 2008. "Potential Future Changes of the Terrestrial Ecosystem Based on Climate Projections by Eight General Circulation Models." *Journal of Geophysical Research* 113: G01–04.

Anderson, M. G. 2008. "Conserving Forest Ecosystems: Guidelines for Size, Condition and Landscape Requirements. In *Saving Biological Diversity: Balancing Protection of Endangered Species and Ecosystems*, ed. R. A. Askins, G. D. Dreyer, G. R. Visgilio, and D. M. Whitelaw, 119–36. New York: Springer-Verlag.

Angelsen, A., P. Jagger, R. Babigumira, B. Belcher, and N.J. Hogarth. 2014. "Environmental Income and Rural Livelihoods: A Global-Comparative Analysis." *World Development* 64: 12–28.

Arneth, A., C. Brown, and M. D. A. Rounsevell. 2014. "Global Models of Human Decision-Making for Land-Based Mitigation and Adaptation Assessment." *Nature Climate Change* 4 (2014): 550–57.

Badola, R., and S. A. Hussain. 2005. "Valuing Ecosystem Functions: An Empirical Study on the Storm Protection Function of Bhitarkanika Mangrove Ecosystem, India." *Environmental Conservation* 32 (1): 85–92.

Barney, K., and K. Canby. 2011. *EU FLEGT Facility, Baseline Study 2, Lao PDR: Overview of Forest Governance, Markets and Trade*. Washington, DC and Brussels: Forest Trendsand European Forest Institute, European FLEGT Facility.

Bates, B. C., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof, eds. 2008. "Climate Change and Water." Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Beniston, M., and D. B. Stephenson. 2004. "Extreme Climatic Events and Their Evolution under Changing Climatic Conditions." *Global and Planetary Change* 44: 1–9.

Berkes, F., and C. Folke, eds. 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. New York: Cambridge University Press.

Bolte, A., C. Ammer, M. Lof, P. Madsen, G. J. Nabuurs, P. Schall, P. Spathelf, and J. Rock. 2009. "Adaptive Forest Management in Central Europe: Climate Change Impacts, Strategies, and Integrative Concepts." *Scandinavian Journal of Forest Research* 24 (6): 473–82.

Brooks, N. 2003. *Vulnerability, Risk and Adaptation: A Conceptual Framework*. Working Paper 38. Norwich, U.K.: Tyndall Centre for Climate Change Research.

Bruijnzeel, L. A., I. R. Calder, and R. A. Vertessy. 2004. "Forest Hydrology: Impacts of Forest Conversion on Streamflow." In *The Encyclopedia of Forest Sciences*, ed. J. Burley, J. Evans, and J. A. Youngquist, 350–58. Oxford: Elsevier.

Calder, I. R. 2002. "Forests and Hydrological Services: Reconciling Public and Science Perceptions." *Land Use and Water Resources Research* 2: 1–12.

Cambridge Conservation Initiative. 2012. *Effectiveness of Ecosystem-Based Approaches to Adaptation: A Critical Review of Current Evidence*. At www.conservation.cam.ac.uk.

CBD (Convention on Biological Diversity). 2009. "Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change Convention on Biological Diversity." Technical Series 41: 1–127. Montreal.

CETI S.A. (Centro de Estudios de Transporte e Infraestructura S.A.) 2011. *Transferencia de los servicios de Agua Potable y Saneamiento por parte del SANAA. Informe No. 6 (Final. Versión Preliminar). Tomo IV. Factores clave institucionales y operacionales*. Buenos Aires.

Colfer, C. J. P., D. Sheil, and M. Kishi. 2006. *Forests and Human Health: Assessing the Evidence*. Occasional Paper No. 45. Bogor, Indonesia: Center for International Forestry Research.

Colfer, C. J. P., ed. 2008. *Human Health and Forests: A Global Overview of Issues, Practice and Policy*. London: Earthscan.

Das, S. 2007. "Valuation of the Storm Protection Services of the Mangroves of Orissa." SANDEE Working Paper No 25-07, Kathmandu, Nepal.

Das, S., and J. R. Vincent. 2009. "Mangroves Protected Villages and Reduced Death Toll during Indian Super Cyclone." *Proceedings of the National Academy of Sciences of the United States of America* 106 (18): 7357–60.

Day, J. W., Jr., D. F. Boesch, E. J. Clairain, G. P. Kemp, S. B. Laska, W. J. Mitsch, K. Orth et al. "Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita." *Science* 315 (5819): 1679–84.

Dessai, S., and R. Wilby. 2011. *How Can Developing Country Decision Makers Incorporate Uncertainty about Climate Risks into Existing Planning and Policymaking Processes?* Washington, DC: World Resources Institute.

Dudley, N., S. Stolton, A. Belokurov, L. Krueger, N. Lopoukhine, K. MacKinnon, T. Sandwith, and N. Sekhran, eds. 2010. *Natural Solutions: Protected Areas Helping People Cope with Climate Change*. Washington DC: International Union for Conservation of Nature–World Commission on Protected Areas, The Nature Conservancy, United Nations Development Programme, Wildlife Conservation Society, World Bank, and World Wildlife Fund.

Dwyer, M. B. 2011. "Building the Politics Machine: Tools for 'Resolving' the Global Land Grab." Paper presented at the International Conference on Global Land Grabbing, 6–8 April.

Eakin, H., and A. L. Luers. 2006. "Assessing the Vulnerability of Social-Environmental Systems." *Annual Review of Environment and Resources* 31: 365–94.

Ebert, A., J. Welz, D. Heinrichs, K. Krellenberg, and B. Hansjürgens. 2010. "Socio-environmental Change and Flood Risks: The Case of Santiago de Chile." *Erdkunde* 64: 303–13.

Enfors, E. I., and L. J. Gordon. 2008. "Dealing with Drought: The Challenge of Using Water System Technologies to Break Dryland Poverty Traps." *Global Environmental Change* 18 (4): 607–16.

Fabricius, C., C. Folke, G. Cundill, and L. Schultz. 2007. "Powerless Spectators, Coping Actors, and Adaptive Co-Managers: A Synthesis of the Role of Communities in Ecosystem Management." *Ecology and Society* 12 (1): 1–16.

FAO (Food and Agriculture Organization). 2004. *Payment Schemes for Environmental Services in Watersheds.* Land and Water Discussion Paper, Vol. 3. Rome.

FAO (Food and Agriculture Organization)/WFP (World Food Programme). 2011. *Special Report: FAO/WFP Crop and Food Security Assessment Mission to Lao PDR*. Rome.

Fisher, M., M. Chaudhury, and B. McCusker. 2010. "Do Forests Help Rural Households Adapt to Climate Variability? Evidence from Southern Malawi.» *World Development* 38: 1241–50.

Folke, C. 2002. *Social-Ecological Resilience and Behavioural Responses*. Beijer Discussion Paper. Stockholm: Beijer International Institute of Ecological Economics.

Foppes, J., and D. Samontry. 2010. *Technical Report: Assessment of the Values of Non-Timber Forest Products (NTFP) in Lao PDR. With special reference to National Production Forest Areas (PFAs) supported by the Sustainable Forestry through Rural Development (PSFM) project*. Department of Forestry, Ministry of Agriculture and Forestry.

Fujita, W. 2000. "Farmer's Views of the Forest: Perceptions of the Forest and the Natural Environment in Northeast Thailand." *Southeast Asian Studies* 38 (1).

Füssel, H. M. 2007a. "Vulnerability: A Generally Applicable Conceptual Framework for Climate Change Research." *Global Environmental Change* 17 (2): 155–67.

———. 2007b. "Adaptation Planning for Climate Change: Concepts, Assessment Approaches, and Key Lessons." *Sustainability Science* 2: 265–75.

Garrity, D. P., F. K. Akinnifesi, O. C. Ajayi, S. G. Weldesemayat, J. C. Mowo, A. Kalinganire, M. Larwanou, and J. Bayala. 2010. "Evergreen Agriculture: A Robust Approach to Sustainable Food Security in Africa." *Food Security* 2 (3): 197–214.

Gerten, D., S. Schaphoff, U. Haberlandt, W. Lucht, and S. Sitch. 2004. "Terrestrial Vegetation and Water Balance—Hydrological Evaluation of a Dynamic Global Vegetation Model." *Journal of Hydrology* 286: 249–70.

Gill, S. E., J. F. Handley, A. R. Ennos, and S. Pauleit. 2007. "Adapting Cities for Climate Change: The Role of the Green Infrastructure." *Built Environment* 33 (1): 115–33.

Giorgi, F. 2006. "Climate Change Hot-Spots." *Geophysical Research Letters* 33: L08707.

Goller, R., W. Wilcke, M. J. Leng, H. J. Tobschall, K. Wagner, C. Valarezo, and W. Zech. 2005. "Tracing Water Paths through Small Catchments under a Tropical Montane Rain Forest in South Ecuador by an Oxygen Isotope Approach," *Journal of Hydrology* 308: 67–80.

Guariguata, M. 2009. "El Manejo Forestal en el Cotexto de la Adaptación al Cambio Climático." *Revista de Estudios Sociales* 32: 98–112.

Gunderson, L. H., and C. S. Holling, eds. 2002. *Panarchy: Understanding Transformation in Human and Natural Systems.* Washington, DC: Island Press.

Gunderson, L. H., S. R. Carpenter, C. Folke, P. Olsson, and G. Peterson. 2006. "Water RATs (Resilience, Adaptability, and Transformability) in Lake and Wetland Social-Ecological Systems." *Ecology and Society* 11 (1): 16.

Hagerman, S. M., H. Dowlatabadi, T. S. Satterfield, and T. McDaniels. 2010. "Expert Views on Biodiversity Conservation in an Era of Climate Change." *Global Environmental Change* 20: 192–207.

Harmeling, S., B. Schinke, C. Haberstroh, and S. Kreft. 2012. *Global Climate Risk Index. Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2010 and 1991 to 2010*. Berlin: Germanwatch Institute.

Haxeltine, A., and I. C. Prentice. 1996. "BIOME 3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability and Competition among Plant Functional Types." *Global Biogeochemical Cycles* 10: 693–709.

Holdridge, L. R. 1947. "Determination of World Plant Formations from Simple Climatic Data." *Science* 105: 367–68.

Holling, C. S. 1973. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4: 1–23.

———. 1978. *Adaptive Environmental Assessment and Management*. Chichester, NY: John Wiley and Sons.

Holling, C. S., and G. K. Meffe. 1996. "Command and Control and the Pathology of Natural Resource Management." *Conservation Biology* 10 (2): 328–37.

Holling, C. S., and S. Sanderson. 1996. "Dynamics of (Dis)harmony in Ecological and Social Systems." In *Rights to Nature: Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment*, ed. S. Hanna, C. Folke, and K.-G. Maeler, 57–86. Washington, DC: Island Press.

Huntjens, P., C. Pahl-Wostl, and J. Grin. 2010. "Climate Change Adaptation in European River Basins." *Regional Environmental Change*.

Ilstedt, U., A. Malmer, E. Verbeeten, and D. Murdiyarso. 2007. "The Effect of Afforestation on Water Infiltration in the Tropics: A Systematic Review and Meta-Analysis." *Forest Ecology and Management* 251 (1–2): 45–51.

Imbach, P., L. Molina, B. Locatelli, O. Roupsard, G. Mahé, R. Neilson, L. Corrales, M. Scholze, and P. Ciais. 2012. "Modeling Potential Equilibrium States of Vegetation and Terrestrial Water Cycle of Mesoamerica under Climate Change Scenarios." *Journal of Hydrometeorology* 13 (2): 665–80.

IPCC (Intergovernmental Panel on Climate Change). 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability (Third Assessment Report)*. Cambridge, U.K.: Cambridge University Press.

———. 2013. "Summary for Policymakers." In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, U.K.: Cambridge University Press.

———. 2014. "Summary for Policymakers." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group 11 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 1–32. Cambridge, U.K.: Cambridge University Press.

Jintrawet, A., and S. Chinvanno. 2012. *Climate Change in Southeast Asia and Assessment on Impact, Vulnerability and Adaptation on Rice Production and Water Resources*. Kobe, Japan: Asia-Pacific Network for Global Research.

Kaimowitz, D. 2005. "Useful Myths and Intractable Truths: The Politics of the Link between Forests and Water in Central America." In *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management,* ed. M. Bonell and L. A. Bruijnzeel, 86–98. Cambridge, U.K.: Cambridge University Press.

Kandlikar, M., J. Risbey, and S. Dessai. 2005. "Representing and Communicating Deep Uncertainty in Climate-Change Assessments." *Comptes Rendu Geoscience* 337: 443–55.

Kenney-Lazar, M. 2010. *Land Concessions, Land Tenure, and Livelihood Change: Plantation Development in Attapeu Province, Southern Laos*. Vientiane: National University of Laos.

Krawchuk, M. A., M. A. Moritz, M.A. Parisien, J. Van Dorn, and K. Hayhoe. 2009. "Global Pyrogeography: the Current and Future Distribution of Wildfire." *PLOS ONE* 4.

Lefroy, R., L. Collet, and C. Grovermann. 2010. *Study on Potential Impacts of Climate Change on Land Use in the Lao PDR*. Cali, Colombia: International Center for Tropical Agriculture.

Levy, M., S. Babu, and K. Hamilton. 2005. "Ecosystem Conditions and Human Well-Being." In *Ecosystems and Human Well-Being*, *Volume 1: Current State and Trends*, Millennium Ecosystem Assessment, 123–64. Washington, DC: Island Press.

Lin, B. B. 2007. "Agroforestry Management as an Adaptive Strategy against Potential Microclimate Extremes in Coffee Agriculture." *Agricultural and Forest Meteorology* 144 (1–2): 85–94.

Lin, B., I. Perfecto, and J. Vandermeer. 2008. "Synergies between Agricultural Intensification and Climate Change Could Create Surprising Vulnerabilities for Crops." *Bioscience* 58: 847–54.

———. 2010. "The Role of Agroforestry in Reducing Water Loss through Soil Evaporation and Crop Transpiration in Coffee Agroecosystems." *Agricultural and Forest Meteorology* 150 (4): 510–18.

Liu, Y. Q., J. Stanturf, and S. Goodrick. 2010. "Trends in Global Wildfire Potential in a Changing Climate." *Forest Ecology and Management* 259: 685–97.

Liu, W., W. Liu, H. Lu, D. Wenping, and H. Li. 2011. "Runoff Generation in Small Catchments under a Native Rain Forest and a Rubber Plantation in Xishuangbanna, Southwestern China." *Water and Environment Journal* 25: 138–47.

Locatelli, B. 2011. “Synergies between Adaptation and Mitigation in a Nutshell.” COBAM Brief. Bogor, Indonesia: Center for International Forestry Research.

Locatelli, B., and R. Vignola. 2009. “Managing Watershed Services of Tropical Forests and Plantations: Can Meta-Analyses Help?” *Forest Ecology and Management* 258 (9): 1864–70.

Locatelli, B., M. Brockhaus, A. Buck, and I. Thompson. 2010. “Forests and Adaptation to Climate Change: Challenges and Opportunities.” In *Forest and Society: Responding to Global Drivers of Change,* ed. G. Mery, P. Katila, G. Galloway, R. I. Alfaro, M. Kanninen, M. Lobovikov, and J. Varjo, 21–42. IUFRO World Series Vol. 25. Vienna: International Union of Forest Research Organizations.

Locatelli, B., M. Kanninen, M. Brockhaus, C. J. P. Colfer, D. Murdiyarso, and H. Santoso. 2008. “Facing an Uncertain Future: How Forests and People Can Adapt to Climate Change.” Forest Perspectives No. 5: 1–86. Bogor, Indonesia: Center for International Forestry Research.

Louman B., A. Fischlin, P. Glueck, J. Innes, A. Lucier, J. Parrotta, H. Santoso, I. Thompson, and A. Wreford. 2009. “Forest Ecosystem Services: A Cornerstone for Human Well-being.” In *Adaptation of Forests and People to Climate Change. A Global Assessment Report*, ed. R. Seppälä, A. Buck, and P. Katila, 15–28. Helsinki: International Union of Forest Research Organizations.

MA (Millennium Ecosystem Assessment). 2003. *People and Ecosystems: A Framework for Assessment and Action*. Washington, DC: Island Press.

———. 2005. *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press.

Mawdsley, J. R., R. O’Mailley, and D. S. Ojima. “A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation.” *Conservation Biology* 23(5): 1080–89.

McCarthy, J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White, eds. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge, U.K.: Cambridge University Press.

McDaniels, T. 1995. “Using Judgment in Resource Management: An Analysis of a Fisheries Management Decision.” *Operations Research* 43 (3): 415–26.

McDaniels, T., T. Mills, R. Gregory, and D. Ohlson. 2012. “Using Expert Judgments to Explore Robust Alternatives for Forest Management under Climate Change.” *Risk Analysis* 32 (12): 2098–112..

McSweeney, K. 2005. “Natural Insurance, Forest Access, and Compounded Misfortune: Forest Resources in Smallholder Coping Strategies Before and After Hurricane Mitch, Eastern Honduras.” *World Development* 33: 1453–71.

MECV (Ministère de l’Environnement et du Cadre de Vie). 2007. *Programme d’Action National et d’Adaptation (NAPA) à la Variabilité et aux Changements Climatiques*. Ouagadougou.

Metzger, M. J., and D. Schröter. 2006. “Towards a Spatially Explicit and Quantitative Vulnerability Assessment of Environmental Change in Europe.” *Regional Environmental Change* 6: 201–16.

Metzger, M. J., R. Leemans, and D. Schröter. 2005. “A Multidisciplinary Multi-Scale Framework for Assessing Vulnerabilities to Global Change.” *International Journal of Applied Earth Observation and Geoinformation* 7 (4): 253–67.

Mitchell, T. D., T. R. Carter, P. D. Jones, M. Hulme, and M. New. 2003. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). *Journal of Climate*: submitted (August 2003).

Morgan, M. G., L. Pitelka, and E. Shevliakova. 2001. "Elicitation of Expert Judgments of Climate Change Impacts on Forest Ecosystems." *Climatic Change* 49: 279–307.

Moritz, M. A., M. A. Parisien, E. Batllori, M. A. Krawchuk, J. Van Dorn, D. J. Ganz, and K. Hayhoe. 2012. "Climate Change and Disruptions to Global Fire Activity." *Ecosphere* 3: 1–22.

Morris, J. 2007. "Ecological Engineering in Intertidial Saltmarshes." *Lagoons and Coastal Wetlands in the Global Change Context: Impacts and Management Issues Developments in Hydrobiology* 192: 161–68.

Mortimore, M. 2010. "Adapting to Drought in the Sahel: Lessons for Climate Change." *Wiley Interdisciplinary Reviews: Climate Change*, 1 (1): 134–43.

Mortimore, M., and W. M. Adams. 2001. "Farmer Adaptation, Change and Crisis in the Sahel." *Global Environmental Change* 11 (1): 49–57.

Mustelin, J., R. G. Klein, B. Assaid, T. Sitari, M. Khamis, A. Mzee, and T. Haji. 2010. "Understanding Current and Future Vulnerability in Coastal Settings: Community Perceptions and Preferences for Adaptation in Zanzibar, Tanzania." *Population and Environment* 31: 371–98.

NSC (National Statistics Centre). 2006. *Results from the Population and Housing Census 2005*. Steering Committee for Census of Population and Housing. Vientiane, Lao PDR.

OECD/SWAC (Organisation for Economic Co-operation and Development/Sahel and West Africa Club). 2009. *Regional Atlas on West Africa*. West African Studies. Paris: OECD Publishing.

Olsson, P., C. Folke, and F. Berkes. 2004. "Adaptive Comanagement for Building Resilience in Social–Ecological Systems." *Environmental Management* 34 (1): 75–90.

Orlove, B. 2005. "Human Adaptation to Climate Change: A Review of Three Historical Cases and Some General Perspectives." *Environmental Science and Policy* 8 (6): 589–600.

Paavola, J. 2008. "Livelihoods, Vulnerability and Adaptation to Climate Change in Morogoro, Tanzania." *Environmental Science and Policy* 11 (7): 642–54.

Pacific Climate Impacts Consortium. n.d. Regional Analysis Tool (BETA version). *Pacific Climate Impacts Consortium*. Retrieved July 23 and 24, 2012, from tools.pacificclimate.org/select.

Patt, A., and S. Dessai. 2005. "Communicating Uncertainty: Lessons Learned and Suggestions for Climate Change Assessment." *Comptes Rendus Geoscience* 337: 425–41.

Pattanayak, S. K., and R. Kramer. 2001. "Worth of Watersheds: A Producer Surplus Approach for Valuing Drought Control in Eastern Indonesia." *Environment and Development Economics* 6 (1): 123–45.

Poveda, G., P. R. Waylen, and R. S. Pulwarty. 2006. "Annual and Inter-Annual Variability of the Present Climate in Northern South America and Southern Mesoamerica." *Palaeogeography, Palaeoclimatology, Palaeoecology* 234 (1): 3–27.

Pramova, E., B. Locatelli, H. Djoudi, and O. Somorin. 2012a. "Forests and Trees for Social Adaptation to Climate Variability and Change." *WIREs Climate Change* 3: 581–96.

Pramova, E., B. Locatelli, M. Brockhaus, and S. Fohlmeister. 2012b. "Ecosystem Services in the National Adaptation Programmes of Action." *Climate Policy* 12 (4): 393–409.

Prasetiamartati, B., H. S. Tai, N. Santoso, R. Mustikasari, and C. Syah. 2008. "Mangrove Forest and Charcoal Production: Case of Batu Ampar, West Kalimantan." Paper Submitted for IASC 2008 Global Conference.

Prentice, I. C., M. T. Sykes, M. Lautenschlager, S. P. Harrison, O. Denissenko, and P. J. Bartlein. 1993. "Modelling Global Vegetation Patterns and Terrestrial Carbon Storage at the Last Glacial Maximum." *Global Ecology and Biogeography Letters* 3: 67–76.

Rafanoharana, S. C., B. Locatelli, and A. J. M. Russell. 2012a. *An Analysis of Climate Change Scenarios and Their Impacts on Ecosystem Services in the Rio Guacerique Watershed, Honduras*. Draft Technical Report for PROFOR. Bogor, Indonesia: Center for International Forestry Research.

———. 2012b. *An Analysis of Climate Change Scenarios and Their Impacts on Ecosystem Services in Ziro-Sissili, Burkina Faso*. Draft Technical Report for PROFOR. Bogor, Indonesia: Center for International Forestry Research.

———. 2012c. *An Analysis of Climate Change Scenarios and Their Impacts on Ecosystem Services in Savannakhet, Lao PDR*. Draft Technical Report for PROFOR. Bogor, Indonesia: Center for International Forestry Research.

Reid, H., and S. Huq. 2005. "Climate Change, Biodiversity and Livelihood Impacts." In *Tropical Forests and Adaptation to Climate Change: In Search of Synergies*, ed. C. Robledo, M. Kanninen, and L. Pedroni, 57–70. Bogor, Indonesia: Center for International Forestry Research.

Reyer, C., M. Guericke and P. L. Ibisch. 2009. "Climate Change Mitigation via Afforestation, Reforestation and Deforestation Avoidance—And What About Adaptation to Environmental Change?" *Environment and Urbanization* 20(1): 207–29.

Reyes, L. 2006. Problemática de la Calidad del Agua del Acueducto de Tegucigalpa. In XXII Congreso de Centroamérica y Panamá de Ingeniería Sanitaria y Ambiental "Superación Sanitaria y Ambiental: El Reto". Panamá. At www.bvsde.paho.org/bvsaidis/centroa22/Ponencia42.pdf.

SANAA (Servicio Autónomo Nacional de Acueductos y Alcantarillados) and ICF (Instituto Nacional de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre). 2011. *Plan de Protección y Manejo de la Sub-Cuenca del Río Guacerique*. Tegucigalpa, Honduras.

Schoenweger, O., and A. Uellenberg. 2009. "Foreign Direct Investment (FDI) in Land in the Lao PDR." Eschborn, Germany: GTZ.

Scholze, M., W. Knorr, N. W. Arnell, and I. C. Prentice. 2006. "A Climate-Change Risk Analysis for World Ecosystems." *Proceedings of the National Academy of Sciences of the United States of America* 103: 13116–20.

Schumann, G., P. Ngaosrivathana, B. Soulivanh, S. Kenpraseuth, K. Onmanivong, K.Vongphansipraseuth, and C. Bounkhong. 2006. "Study on State Land Leases and Concessions in Lao PDR." Lao-German Land Policy Development Project, Land Policy Study No. 4. Vientiane, Lao PDR: GTZ.

Scott, D. F., L. A. Bruijnzeel, R. A. Vertessy, and I. R. Calder. 2004. "Forest Hydrology: Impacts of Forest Plantations on Streamflow." In *The Encyclopedia of Forest Sciences,* ed. J. Burley, J. Evans, and J. A. Youngquist, 367–77. Oxford: Elsevier.

Seppälä, R., A. Buck, and P. Katila, eds. 2009. *Adaptation of Forests and People to Climate Change. A Global Assessment Report*. IUFRO World Series Vol. 22. Helsinki: International Union of Forest Research Organizations.

SERNA (Secretaria de Recursos Naturales y Ambiente). 2000. Primera Comunicación de Honduras a la Convención Marco de las Naciones Unidas sobre Cambio Climático. Año de Referencia 1995. Tegucigalpa, Honduras.

Shackleton, C., C. O. Delang, S. Shackleton, and P. Shanley. 2011. "Non-timber forest products: Concept and definitions." In *Non-Timber Forest Products in the Global Context*, ed. S. Shackleton, C. Shackleton, and P. Shanley. Heidelberg: Springer.

SIB. 2012. *Système d'Information sur la Biodiversité en Suisse: Changements Climatiques et Biodiversité* Online, last visit 31 October 2013.

Sitch, S., B. Smith, I. C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J. Kaplan et al. 2003. "Evaluation of Ecosystem Dynamics, Plant Geography and Terrestrial Carbon Cycling in the LPJ Dynamic Vegetation Model." *Global Change Biology* 9: 161–85.

Smit, B., I. Burton, R. J. T. Klein, and R. Street. 1999. "The Science of Adaptation: A Framework for Assessment." *Mitigation and Adaptation Strategies for Global Change* 4: 199–213.

Smith B., I. C. Prentice, and M. T. Sykes. 2001. "Representation of Vegetation Dynamics in the Modelling of Terrestrial Ecosystems: Comparing Two Contrasting Approaches within European Climate Space." *Global Ecology and Biogeography* 10: 621–37.

SOGREAH Consultants. 2004. *Proyecto de Abastecimiento de Agua para Tegucigalpa. Informe de Síntesis.* Indentificación No. 35 0034.I4*.*

Stephenson, N. L., A. J. Das, R. Condit, S. E. Russo, P. J. Baker, N. G. Beckman, D. A. Coomes et al. 2014. "Rate of Tree Carbon Accumulation Increases Continuously with Tree Size" (letter). *Nature* 507 (6 March): 90–93.

Takasaki, Y., B. L. Barham, and O. T. Coomes. 2004. "Risk Coping Strategies in Tropical Forests: Floods, Illnesses, and Resource Extraction." *Environment and Development Economics* 9 (1): 203–24.

Tallis, H., Z. Ferdana, and E. Gray. 2008. "Linking Terrestrial and Marine Conservation Planning and Threats Analysis." *Conservation Biology* 22:120–30.

TEEB (The Economics of Ecosystems and Biodiversity). 2009. *The Economics of Ecosystems and Biodiversity for National and International Policy Makers – Summary: Responding to the Value of Nature*. Geneva.

Tockner, K., and J. A. Stanford. 2002. "Riverine Flood Plains: Present State and Future Trends." *Environmental Conservation* 29: 308–30.

Tougiani, A., C. Guero, and T. Rinaudo. 2009. "Community Mobilisation for Improved Livelihoods through Tree Crop Management in Niger." *GeoJournal* 74 (5): 377–89.

Tri, N. H., W. N. Adger, and P. M. Kelly. 1998. "Natural Resource Management in Mitigating Climate Impacts: The Example of Mangrove Restoration in Vietnam." *Global Environmental Change* 8 (1): 49–61.

TroFCCA (Tropical Forests and Climate Change Adaptation). 2009. *Reportes de Consultorías Desarrolladas en la Subcuenca del Río Guacerique*. Costa Rica: Tropical Agricultural Research and Higher Education Center.

———. 2012. "TroFCAA Methods and Activities." Centre for International Forestry Research. At www.cifor.org/trofcca/the-project/methods-and-activities.html.

Turner II, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L.Christensen, N. Eckley et al. 2003. "A Framework for Vulnerability Analysis in Sustainability Science." *Proceedings of the National Academy of Sciences of the United States of America* 100: 8074–79.

UNDP (United Nations Development Programme). 2001. "Advancing Rural Development." *National Human Development Report*. Lao PDR: UNDP.

UNDP (United Nations Development Programme–Honduras). 2010. *Project/Program Proposal. Addressing Climate Change Risks on Water Resources in Honduras: Increased Systemic Resilience and Reduced Vulnerability of the UrbanPoor.* At www.adaptation-fund.org/sites/default/files/Hondorus%20Project_0.pdf.

UNEP (United Nations Environment Programme). 2013. *Building Resilience of Ecosystems for Adaptation*. Nairobi, Kenya.

van Vuuren, D. P., and L. F. Bouwman. 2005. "Exploring Past and Future Changes in the Ecological Footprint of World Regions." *Ecological Economics* 52 (1): 43–62.

Venema, H. D., E. J. Schiller, and B. Bass. 1996. "Factor Biases and Promoting Sustainable Development: Adaptation to Drought in the Senegal River Basin." *Mitigation and Adaptation Strategies for Global Change* 1: 139–65.

Verchot, L. V., M. Van Noordwijk, S. Kandji, T. Tomich, C. Ong, A. Albrecht, J. Mackensen, C. Bantilan, K. V. Anupama, and C. Palm. 2007. "Climate Change: Linking Adaptation and Mitigation through Agroforestry." *Mitigation and Adaption Strategies for Global Change* 12: 901–18.

Vignola, R., T. L. McDaniels, and R. W. Scholz. 2010. "Decision-making by Upstream Farmers Regarding Ecosystem Services: Factors Affecting Soil Conservation Efforts in Costa Rica Rica." *Land Use Policy* 27(4): 1132–42.

———. 2012. "Negotiation Analysis for Mechanisms to Deliver Ecosystem Services: The Case of Soil Conservation in Costa Rica." *Ecological Economics* 75: 22–31.

Walker, B., L. Gunderson, A. Kinzig, C. Folke, S. Carpenter, and L. Schultz. 2006. "A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-ecological Systems." *Ecology and Society* 11 (1): 13.

Wetlands International. n.d. "Building with Nature for Coastal Resilience." At www.wetlands.org/WatchRead/Currentpublications/tabid/56/mod/1570/articleType/ArticleView/articleId/3475/Building-with-nature-for-coastal-resilience.aspx

World Bank. 2009. *Convenient Solutions to an Inconvenient Truth: Ecosystem-Based Approaches to Climate Change*. Environment Department. Washington, DC.

———. 2010. *The Economics of Adaptation to Climate Change: A Synthesis Report*. Washington, DC.

———. 2011. *Climate Change Knowledge Portal: Climate Country Adaptation Profiles.* Viewed November. Washington, DC.

———. 2012. *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*. Washington, DC.

Wunder, S., A. Angelsen, and B. Belcher. 2014. "Forests, Livelihoods, and Conservation: Broadening the Empirical Base" (editorial). *World Development* 64 (Supp. 1): S1–S11.

Zhang, Q., Y. Guan, and H. Yang, 2008. "ENSO Amplitude Change in Observation and Coupled Models." *Advances in Atmospheric Sciences* 25 (3): 361–66.

Zola, T., and A. Fraser. 2012. "Economic Evaluation of Land-Use Options in Lao PDR." Submitted to RECOFTC–The Center for People and Forests.

EVEN WITH VERY AMBITIOUS CLIMATE CHANGE MITIGATION ACTION, THE WORLD IS LOCKED INTO A PATH OF WARMING CLOSE TO 1.5°C ABOVE PRE-INDUSTRIAL LEVELS BY MIDCENTURY, YIELDING ADAPTATION STRATEGIES CRITICAL.

MANY STUDIES HAVE EXAMINED THE ROLE OF FORESTS AS STORES OF CARBON, BUT RELATIVELY FEW STUDIES HAVE LOOKED AT THE ROLE OF FORESTS IN ADAPTATION TO CLIMATE CHANGE. THE LOW PROFILE OF FORESTS IN THE ADAPTATION DISCUSSION IS SURPRISING, GIVEN THAT THE ROLE OF FORESTS IN GENERATING ECOSYSTEM SERVICES IS WIDELY ACCEPTED AND THERE IS GROWING RECOGNITION OF THE POTENTIAL OF LAND MANAGEMENT AND CONTROL OF LAND USE CHANGES TO CONTRIBUTE TO BOTH ADAPTATION TO AND MITIGATION OF CLIMATE CHANGE.

THIS SYNTHESIS REPORT PRESENTS ON OVERVIEW OF RELEVANT WORK ON THE USE OF FORESTS AND TREES IN ADAPTATION TO CLIMATE CHANGE. IT DRAWS HEAVILY ON THREE NEW CASE STUDIES—A STUDY IN BURKINA FASO ON USING TREES AND FORESTS TO ADAPT THE WOOD ENERGY SUBSECTOR, IN HONDURAS ON HOW FORESTS AND TREES CAN ENHANCE THE RESILIENCE OF MAIN SOURCE OF DRINKING WATER, AND IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC (PDR) ON ROLE OF FORESTS AND ADAPTATION OF SMALLHOLDER AGRICULTURE. THE REPORT DESCRIBES HOW FORESTS CAN ENHANCE SOCIETAL RESILIENCE TO CLIMATE CHANGE WHILE CONTRIBUTING TO MITIGATION. CONCLUSIONS AND RECOMMENDATIONS ARE DRAWN FROM THESE CASE STUDIES AND A BROADER LITERATURE REVIEW.

PROFOR

CATIE
Solutions for environment and development
Soluciones para el ambiente y desarrollo

PROGRAM ON FORESTS (PROFOR)

THE WORLD BANK
1818 H ST NW
WASHINGTON DC 20433 USA

EMAIL: PROFOR@WORLDBANK.ORG
WEBSITE: HTTP://WWW.PROFOR.INFO

Profor is a multi-donor partnership supported by:

Cover Photos:

I3918E/1/07.14