HOW FORESTS ENHANCE RESILIENCE TO CLIMATE CHANGE

What we know about how forests can contribute to adaptation

PROFOR
PROGRAM ON FORESTS

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This report is part of a larger project designed and led by Diji Chandrasekharan Behr (Sr. Natural Resources Specialist, World Bank) on the role of forests in enhancing resilience to climate change (www.profor.info/node/2032). The larger project aims to capture how forests can help reduce the vulnerability of other sectors to climate change. It examines how sustainable management of trees and forests can help strengthen social and physical resilience of systems in three other sectors: agriculture, energy, and water. Using forest and tree management as part of a broader strategy to reduce vulnerability to climate change provides a low-cost option for local landscapes while also contributing to balancing production, livelihood, adaptation, and mitigation goals.

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Acronyms

CIFOR	Center for International Forestry Research
CO2	carbon dioxide
COP	Conference of the Parties
EBA	ecosystem-based adaptation
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NGO	non-governmental organization
NTFP	non-timber forest product
PDR	(Lao) People's Democratic Republic
PROFOR	Program on Forests (World Bank)
REDD+	reducing emissions from deforestation and degradation and enhancing carbon stocks
UNFCCC	United Nations Framework Convention on Climate Change

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

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EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change has gathered substantial evidence on the current and projected impacts of climate change across geographies, ecosystems, and sectors. Even under the most stringent mitigation scenarios, the world's temperature will continue to increase, rendering adaptation strategies a necessity for long-term local and national planning.

A focus on long-term adaptation strategies must not, however, eclipse the need to address severe challenges posed by current aggravated climate variability. Although there are significant subregional differences, rainfall in Africa has declined over the past half-century, and drought events are contributing to a trend of heightened annual and seasonal variability. Southeast Asia has endured climate extremes that include monsoons, tropical cyclones, El Niño/La Niña-Southern Oscillation events, extreme variability in rainfall, and very high temperatures. Future climate change, coupled with a variety of anthropogenic pressures on ecosystems (for example, deforestation due to land conversion, pollution, or human development in floodplains), will only exacerbate these effects.

Human activity is having a significant and at times escalating impact on the world's ecosystems and their ability to provide the critical services that are increasingly important for societal adaptation to climate change. Unsustainable logging and agricultural practices in areas with significant gradients, for example, mean that intensified hurricanes or extreme rainfall events result in disastrous flooding and landslides. In other contexts, anthropogenic impacts are mixed. Some land use changes may combine with increased periods of drought to facilitate large-scale transitions between ecological forms (from savanna to desert, for instance, or from humid to dry forest system). In other cases, some combination of agricultural intensification, migration to cities, and conservation policies result in maintained or increased tree cover and agricultural productivity despite decreases in rainfall.

Forest ecosystems provide human societies with a wide range of provisioning services (for example, wood and non-timber forest products) and regulating services (for example, base flow and storm flow regulation) that reduce vulnerability at the local and sectoral levels. Ecosystem-based adaptation (EBA) is a useful approach for conserving these ecosystem services and reducing vulnerability because it encompasses adaptation strategies that explicitly value the roles of ecosystem services in adaptation to climate change across sectors and scales. Ecosystem-based adaptation strategies can be cost-effective and sustainable, and they generate a wide range of environmental, social, economic, and cultural benefits. Furthermore, EBA has the potential to address both the immediate needs of society and those necessary to prepare for future hazards, and it would be a useful conceptual framework for helping to develop "triple-win" climate-smart agriculture approaches.

Effective use of EBA strategies requires sustainable management and adaptation of forest ecosystems in order to ensure their roles in facilitating the adaptation of people and sectors. This is necessary because land use pressures coupled with climate change will have significant impacts on forest growth, species diversity, and critical functions that underpin the delivery of services. At present, the sectors most dependent on forest ecosystem services have little incentive to invest in forest adaptation.

Mainstreaming forests into the adaptation policies of other sectors requires cross-scale (local to national, and ideally international) and cross-sectoral approaches because ecosystem benefits and management costs generally occur in different locations and in different sectors of society. This will require a greater understanding of how forest ecosystems reduce other sectors' vulnerability to climate change as well as how management of forest ecosystems in certain landscapes can assist with adaptation of forest systems. The implementation of EBA will require adapting and developing institutional arrangements to support cross-sectoral approaches and providing necessary incentives.

1 INTRODUCTION

The global dialogue surrounding the United Nations Framework Convention for Climate Change (UNFCCC) has focused on two strategies for addressing current challenges: mitigation (reducing the accumulation of greenhouse gases, or GHG, in the atmosphere) and adaptation (reducing the vulnerability of societies and ecosystems to the impacts of climate change). Forests feature in both of these strategies. The role of forests as stores of carbon, and therefore in reducing GHG emissions, has been captured in the efforts associated with reducing emissions from deforestation and degradation and enhancing carbon stocks (REDD+). In the area of adaptation, forests have featured less prominently. Only a few National Adaptation Programmes of 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 services is widely accepted.

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 the adaptation of forests themselves in order to prevent a degradation of forest resources and to protect the ecosystem services that society relies on ("adaptation for forests").

Adapting forests to climate change has been the focus of a fair amount of work in the forest sector. One comprehensive study in this area was the International Union of Forest Research Organizations' 2009 publication *Adaptation of Forests and People to Climate Change—A Global Assessment*. This report identified possible changes in forest ecosystems due to climate change. It also documented how varied the response of forests systems to climate change may be. The report pointed to the limited knowledge available to effectively comprehend how forests will respond to climate change, and it advocated strengthening the ability of institutions to deliver on sustainable forest management, which will help with the resilience of forest systems.

Forests can play an important role in adapting to climate change. Many of the provisioning services (for example, wood, fuel, fodder, and NTFPs), regulating services (for example, of water, of soil erosion, and microclimate), and supporting services (for example, nutrient cycling and primary production) that forests provide can contribute to reducing the vulnerability of systems to climate change and as a result enhance their resilience. There is substantial information about when forests contribute these services and where they are beneficial. In some cases there is also information on how the use of forests compares to an alternative source of the same services.

This working paper presents a review of relevant work on forests and the services they provide and of the use of forests and trees in adaptation. It also provides a conceptualization of how to link forest services with their use for adaptation (ecosystem-based adaptation).

2 CLIMATE CHANGE

2.1 What signs of climate change are we already observing?

The Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) states that the human influence on the climate system is evident and that recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems in both industrial and developing countries.

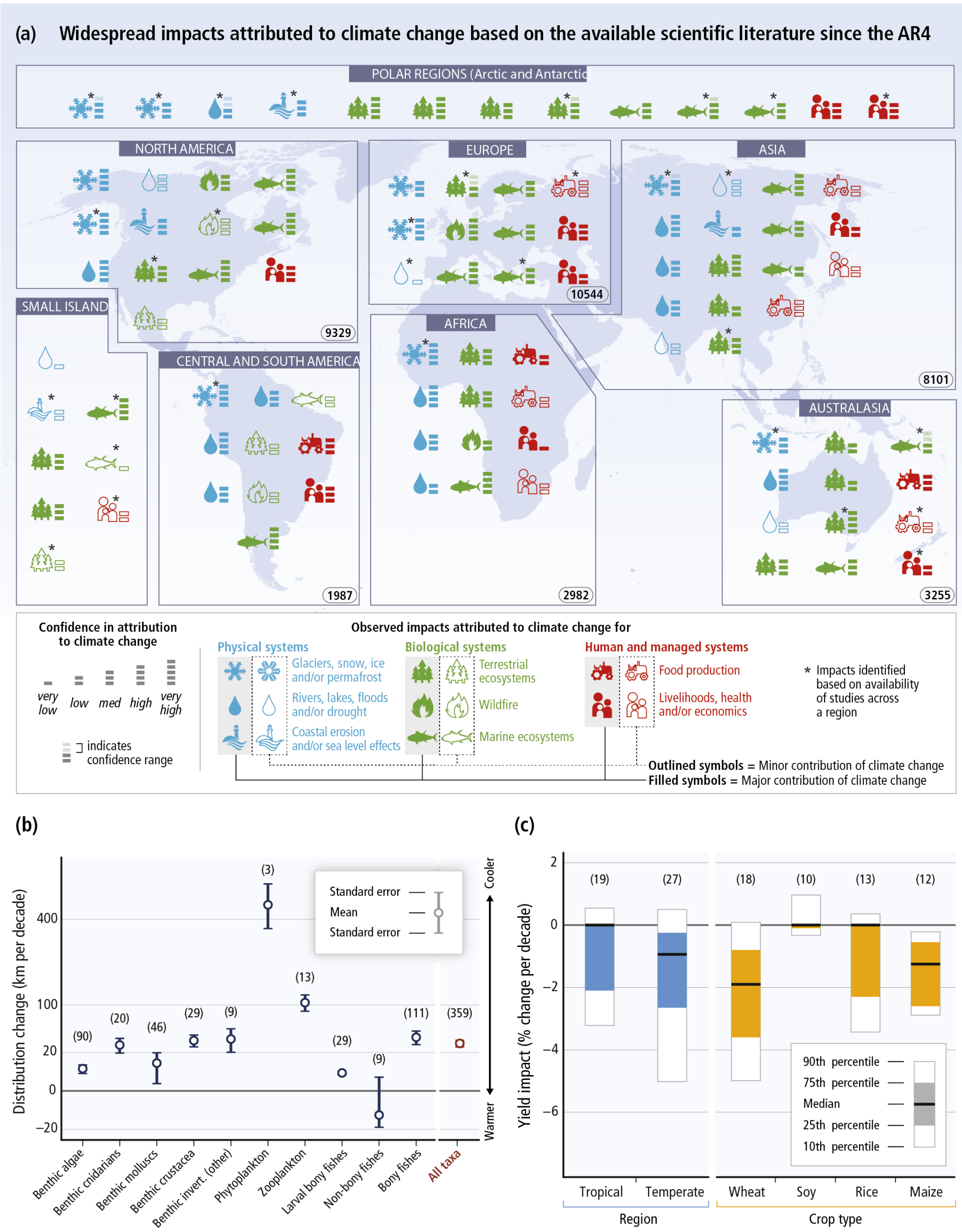
In terms of observed changes in the climate system, IPCC (2014) finds that warming of the climate system has been occurring at unprecedented levels since the 1950s. For the last three decades, the Earth's surface has been successively warmer than in any preceding decade since 1850. The studies associated with the Fifth IPCC Assessment found that ocean warming, especially near the surface and the upper 75 meters, has been largest over the period 1971 to 2010. The report states that it is likely that regions of high surface salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. The IPCC studies found, with a high degree of confidence, that the rate of sea level rise since the mid-nineteenth century has been greater than the mean rate during the previous two millennia (IPCC 2014).

Some of the consequences of these changes include changes in hydrological systems affecting water resources in terms of quantity and quality. Changes in the climate system are also resulting in shifts in the geographic ranges, seasonal activities, migration patterns, abundance, and species interactions of terrestrial, freshwater, and marine species. Climate change studies are also showing that the impacts of the changes have more commonly been negative rather than positive. The infographic produced by the IPCC summarizes the widespread impacts attributed to climate change based on the scientific literature available since the previous report (see Figure 1).

The Fifth IPCC Assessment Report also found that changes in many extreme weather and climate events include a decrease in cold and an increase in warm temperature extremes, an increase in extreme high sea levels, and an increase in the number of heavy rain events in several regions (IPCC 2014). The impacts of these changes are a function of the exposure and vulnerability of the systems. Exposure and vulnerability in turn are influenced by a range of social, economic, and cultural factors and processes (IPCC 2014).

It is clear that 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 ecosystems and societies.

FIGURE 1. IPCC OVERVIEW OF IMPACTS OF CLIMATE CHANGE, 2014



Source: IPCC 2014.

2.2 What will our climate look like in the future?

There have been notable improvements in the models for simulating continental-scale surface temperature, large-scale precipitation, ocean heat content, extreme events, and other measures related to climate change (IPCC 2014). These improved models predict that the continued emission of GHGs will cause further warming and long-lasting changes in all components of the climate system. This in turn will increase the probability of severe, pervasive, and irreversible impacts on people and ecosystems.

The models predict with medium-level confidence that the global mean surface temperature change for the period 2016–35 compared with 1986–2005 will likely range from 0.3oC to 0.7oC (see Figure 2). The models also forecast that the change in precipitation in a warming world will not be uniform, with some regions experiencing greater precipitation while others experience a decrease. It is also forecast that the global mean sea level will continue to rise in the twenty-first century (IPCC 2014).

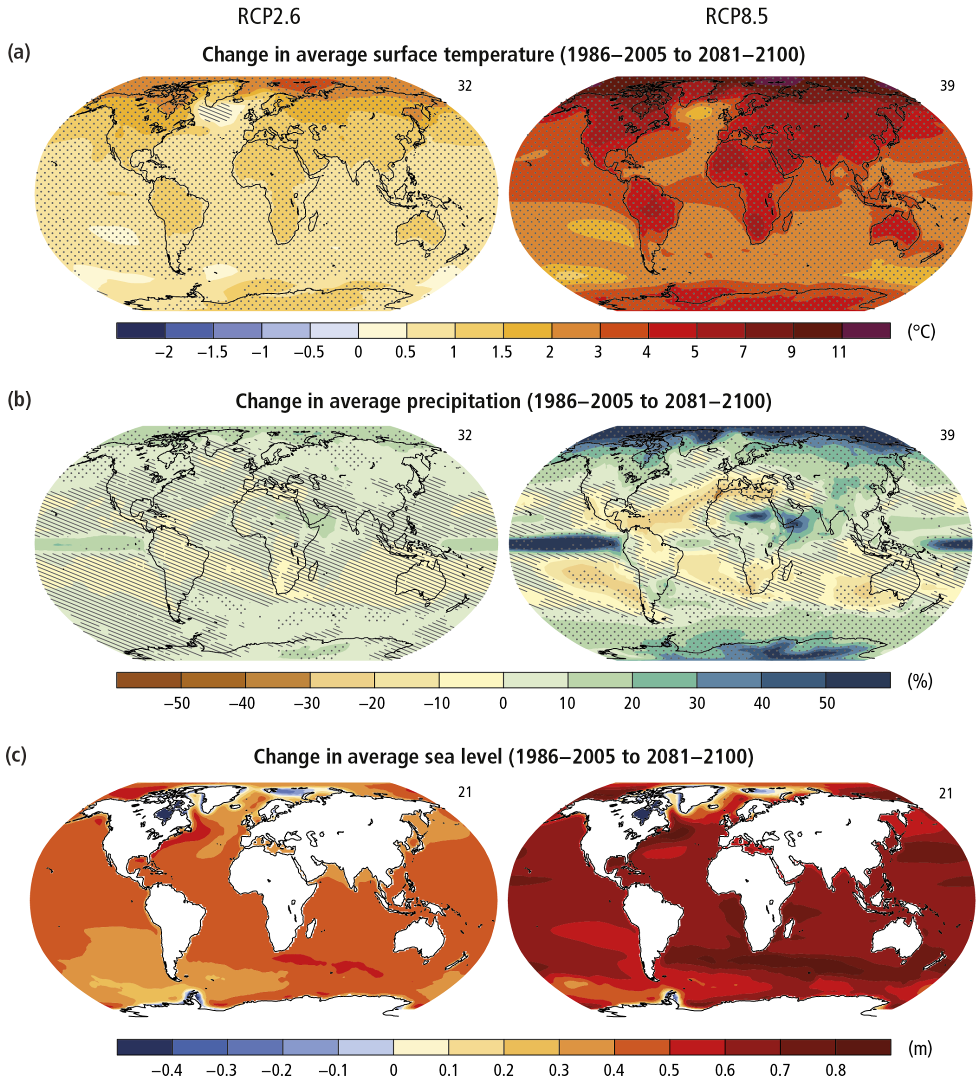
There is growing evidence that climate change will amplify existing risks and create new ones for natural and social systems. For purposes of the IPCC Fifth Assessment, using expert judgment, risk levels were assessed for three time frames: the present, 2030–40, and 2080–2100. There are four key risks that span sectors and regions:

- The risk of severe negative health effects and disruption to livelihoods stemming from storm surges, sea level rise, coastal and inland flooding, and periods of extreme heat
- Systematic risks due to extreme weather events leading to a breakdown of infrastructure networks and critical services
- The risk of food insecurity and loss of rural livelihoods and incomes, especially for poor populations
- The risk of loss of ecosystems, biodiversity, and ecosystem goods, functions, and services (IPCC 2014)

At the regional level, the key future risks are expected to be the following:

- For Africa, the compounded stress on water resources, reduced crop productivity and livelihood and food security, and the spread of vector- and water-borne diseases
- For Asia, increased flood damage to infrastructure, livelihoods, and settlements; increased heat-related human mortality; and increased drought-related water and food shortages
- For Central and South America, reduced water availability, increased flooding and landslides, reduced food production and quality, and the spread of vector-borne diseases (IPCC 2014).

FIGURE 2. MEAN CHANGES IN AVERAGE SURFACE TEMPERATURE, AVERAGE PRECIPITATION, AND AVERAGE SEA LEVEL, 1986–2005 TO 2081–2100



Source: IPCC 2014.

2.3 How will climate change affect key ecosystems?

The impact of climate change will not be uniform around the globe. The poorest regions are expected to face the most difficulty because of their limited capacity to cope and adapt. The unprecedented change in temperatures and the extreme temperatures in the tropics are expected to have significant impacts on agriculture and ecosystems. A series of reports entitled *Turn Down the Heat* (World Bank 2012, 2013, 2014) examines how climate change will affect key terrestrial and marine ecosystems. The main findings from these reports are summarized in this section.

Under a 2°C warming scenario, water availability is projected to decline by 20 percent. The shortfall in water and the impact of variability of precipitation is likely to be felt the most in South Asia, where water and food resources could be at severe risk. In Sub-Saharan Africa, Southeast Asia, and South Asia, warming is expected to affect yields of crops (as is already observed with 0.8°C warming above preindustrial levels). In the Sub-Saharan Africa region, a 1.5°C warming by 2030 is projected to mean about 40 percent of current maize cropping areas will not be suitable for current maize varieties. At higher temperatures, projections are of decreased yields of 15–20 percent for all crops and regions. (World Bank 2013).

Increased temperatures and warming are projected to shift ecosystems, changing species composition and, in some cases, resulting in species extinction. In Africa, savanna ecosystems are projected to shift from grasses to woody plants with increased levels of carbon dioxide (CO_2). Such a shift could reduce the availability of forage for livestock. The change in species composition is projected to negatively affect the livelihood strategies of communities dependent on them. Eventually, any positive effects of CO_2 will be countered by higher temperatures and precipitation. Increased temperatures and ocean acidification are expected to cause major damage to coral reef systems and lead to a loss of fish production (World Bank 2013).

In Southeast Asia, river deltas are expected to face sea level rise and tropical cyclones of increasing intensity. The climatic changes along with human-induced land subsidence will increase the vulnerability of both rural and urban households to flooding, saltwater intrusion, and coastal erosion. Fisheries and aquaculture are likely to be affected by climate change. For the former, primary productivity is expected to decline by 20 percent, and the latter will be affected by saltwater intrusion and flooding. These in turn are likely to have negative consequences for food security. In South Asia, issues of water scarcity and change in precipitation patterns and associated water scarcity are expected to have a negative impact on crop yields. The fertilization from increased CO_2 is expected to offset the negative impacts due to water scarcity. The benefits of additional CO_2, however, diminish with greater warming (World Bank 2013).

In Latin America and the Caribbean, the higher mean temperature and increased frequency of drought are expected to decrease water supply and affect most ecosystems and agroecosystems. The greater risk of drought in turn raises the risk of forest fires, large-scale climate-induced forest degradation (such as forest dieback), and the loss of associated ecosystem services. The changes in precipitation patterns and temperatures are also projected to put small-scale and export agriculture at risk because of their high dependence on rainfed agriculture.

2.4 Some sectoral impacts of climate change

In agriculture, overall there is an expected decrease in crop yields in developing countries (although this varies greatly between countries) (Perry et al. 2004). Reduced soil moisture and evapotranspiration are likely to increase land degradation, salinization, and desertification in some areas. Some of the on-site effects of erosion and salinization are in turn expected to translate into lower crop yields and livestock productivity. For Africa, yields from rainfed crops could be halved by 2020 in some countries, and already compromised fish stocks will be depleted further due to rising water temperature. Inundation of coastal zones and coastal deltas, erosion, negative impacts on fish stock and the availability of water, and degradation of marine ecosystems are anticipated due to extreme weather events.

The water resource sector will be significantly affected by climate change. In Latin America, Asia, and Africa, increasing water stress is a concern for hundreds of millions of people. Decreased availability of freshwater in large river basins in Asia, decreased runoff due to the loss and retreat of glaciers, and overall water shortages will be a constraint. Erosion from severe rainfall and from wind will also affect water. The movement of sediment and the associated agricultural pollutants will affect bodies of water. Some of the anticipated impacts are increased sedimentation of canals, water channels, and dams and the contamination of drinking water. Eroded soil also has a lower capacity to absorb water, which in turn increases runoff and has associated downstream damages.

Water is central to the energy sector. Climate change impacts on the energy sector can stem from the decreased availability of water for hydropower generation, the reduced availability of water for cooling power generators, and changes in temperature and pressure patterns that affect wind and solar power generation (Contretas-Lisperguer and de Cuba 2008).

2.5 Interactions between climate change and anthropogenic drivers of change

The Millennium Ecosystem Assessment 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).
It should be reemphasized that 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 the incremental increases in temperature or rainfall may result in unpredictable and sudden, dramatic changes in the structure and function of ecological systems and in landscape transformations.

3 VULNERABILITY AND CLIMATE CHANGE ADAPTATION

3.1 Understanding vulnerability and resilience to climate change

The concepts of resilience and vulnerability are found in many discussions on climate change adaptation. From a socioecological system perspective, resilience 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).[1]

Many classical approaches to the management of terrestrial resources are based on the assumption that environmental variability could be controlled in order to maximize harvests of key species of commercial value. However, Holling (1973, 1978) and a growing community of practice around resilience and adaptive management have transformed how resource scientists and managers think about forest management and environmental change. The adaptive management approach 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).

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 resilience concept is very useful for understanding the types of management that undermine ecosystem adaptation. However, 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 make resilience less useful as an analytical tool in climate change adaptation research. Instead, we focus here on a proxy for a roughly opposite condition that we can measure more easily based on currently available data: vulnerability.

1. See also Resilience Alliance 2001: www.resalliance

3.1.1 The IPCC approach to understanding vulnerability

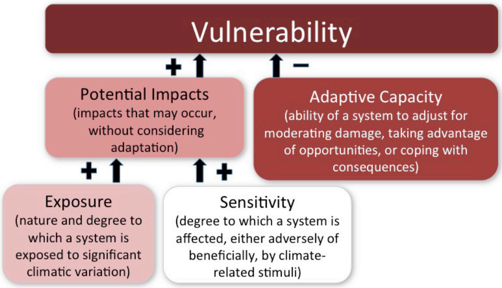
Vulnerability is more of an operational concept. Due to its applications in an array of disaster relief, livelihood development, health management, climate change, psychology, and risk management settings, vulnerability has been defined differently by practitioners and researchers. It has frequently been related to concepts of risk, hazard, sensitivity, exposure, adaptive capacity, resilience, and potential impacts (Brooks 2003; Eakin and Luers 2006). We use the definition of vulnerability proposed by the IPCC, which is now widely accepted within the climate change community (see Metzger, Leemans, and Schröter 2005):

> [T]he degree to which a system is susceptible to, or unable to cope with, 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).

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

The relationships between the primary components of vulnerability (exposure, sensitivity, and adaptive capacity) are illustrated in Figure 3. Based on the IPCC definition of vulnerability, exposure is external to the system, while sensitivity and adaptive capacity are internal.

FIGURE 3. THE COMPONENTS OF VULNERABILITY



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

3.1.2 The components of vulnerability

Using the example of a hypothetical study related to the vulnerability of forest growth to changes in temperature regimes, the primary variables of exposure might relate to the projected average number of peak temperature days per year and the projected rainfall for those same periods. In some studies, ecosystem variables such as watershed hydrological response may

TABLE 1. FACTORS CONTRIBUTING TO VULNERABILITY

	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

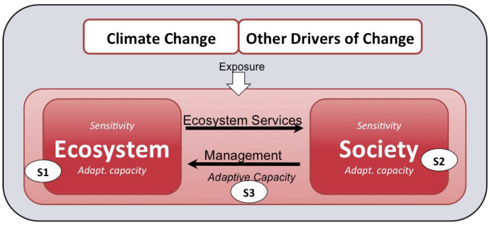
Source: Füssel 2007a.

also be relevant, as might socioeconomic variables (for example, globalization of markets or development assistance) (see O'Brien et al. 2004). As mentioned, sensitivity is a characteristic of the system itself and represents the "dose-response" relationships between the exposure and the effects (that is, sensitivity of tree dynamics to temperature, sensitivity to intensity of wildfires, sensitivity to rainfall). Together, exposure and sensitivity represent the potential impact of climate change on a specific socioecological system (that is, the likelihood of a forest ecosystem and watershed undergoing significant changes due to species loss, forest fires, erosion, and so on). Finally, adaptive capacity is the system's internal ability to modify its characteristics in response to potential climate change impacts. This might relate to the system's ability to continue to provide key ecosystem services through a reorganization of species composition.

Based on work conducted by Turner et al. (2003) and Metzger, Leemans, and Schröter (2005), the Center for International Forestry Research and the Tropical Agricultural Research and Higher Education Center developed a general framework for the assessment of vulnerability in coupled socioecological systems.[2] This approach has been applied to the analysis of vulnerability and the design of adaptation strategies in diverse ecosystem services and different contexts, such as non-timber forest products in West Africa and forest hydrological services in Central America.

Within this model, three main sets of vulnerability criteria (labeled S1-S3) are defined (see Figure 4). The first set (S1) describes the vulnerability of ecosystem services to climate change or variability and other threats. This may include

FIGURE 4. THREE TYPES OF VULNERABILITIES



Source: TroFCCA project.

criteria related to exposure and sensitivity to climate change or variability and ecosystem adaptive capacity as a function of current degradation or other pressures.

The second set (S2) deals with the human system and its vulnerability to the loss of ecosystem services. The sensitivity of the system (for example, dependence on NTFPs or clean water) and its adaptive capacity (for example, availability of substitutes for the lost services) can be used as criteria. For this set, the external drivers of changes must also be taken into account—for example, macroeconomic policies or energy prices.

The third set (S3) considers the adaptive capacity of the system as a whole. It refers to the capacity of human systems to reduce the loss of ecosystem services. Criteria can refer to the capacity of reducing "maladaptation" practices (for example, removing practices that increase pressures on ecosystems) and the capacity to implement forest adaptation.

2. Developed by the TroFCCA project (CIFOR–CATIE, www.cifor.cgiar.org/trofcca).

3.2 From vulnerability to adaptation

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 awareness or designing insurance schemes.

There are many examples of spontaneous adaptation to climate change demonstrated by diverse communities (see Mortimore and Adams 2001; Orlove 2005). But 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. 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).

Many rural communities rely on ecosystem services and everyday resources for their coping strategies (Shackleton and Shackleton 2004) but they do not develop any management strategies for these services and resources, mainly due to the lack of capacity and adequate governance structures. This could lead to increased ecosystem degradation and vulnerability in the long term. 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).

3.2.1 Planning adaptation

Due to the wide range of climatic contexts, ecological systems, and impacted 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 (see Table 2). In most cases, an effective adaptation strategy will require the concerted and coordinated actions of almost all types listed (individuals, collectives, and national governments) to address both short-term and long-term challenges, including capacity building for both responsive and anticipatory adaptation. Consequently, for any given socioecological system, adaptation strategies cannot be imposed as blueprints. They must be tailored to the relevant local economic, environmental, political, and cultural context and 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

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

3.2.2 Local and national stakeholder support

An effective adaptation strategy planning process should start with, and be framed by, vulnerability parameters of relevance to local stakeholders. This process will typically begin with an investigation of existing strategies for dealing with climate variability and of local stakeholder perceptions and understandings of the current and projected climate change and vulnerability contexts (Agrawal 2008).

Local institutions should be considered as key actors in adaptation planning, building on their potential to efficiently detect vulnerability and define possible adaptation responses and outcomes. Furthermore, any adaptation activities (and changes in behaviors) require the active leadership of local leaders and institutions. Therefore, an extensive analysis of, and engagement with, formal and informal institutions is necessary to help ensure that the measures planned will be accepted by the community (Pelling and High 2005; Allen 2006). Any planned adaptation should aim to empower local stakeholders, particularly those who may already be marginalized or more vulnerable (such as women, young people, and minorities) (Allen 2006).

Local relevance and ownership, however, might be insufficient for successful adaptation because local actions will generally require coordinated and supporting actions by relevant national institutions, and national policies and programs have a strong influence on local adaptive capacity.

3.2.3 Addressing current vulnerability but avoiding "maladaptation"

In many developing country contexts, there may be some difficulty in distinguishing between adaptation to climate change and what some observers would refer to as "development as usual." This confusion is somewhat justified initially because, in many contexts, the current levels of vulnerability (given existing climate, market, and governance conditions) must be addressed before stakeholders can hope to implement adaptation strategies focused on the potential impacts of long-term climate change. Therefore, reducing current vulnerability must be recognized as an essential first step in the process of adaptation to climate change. A society that is less vulnerable to current threats has the potential to be more adaptive to future changes (Locatelli et al. 2008).

Adaptation efforts can focus on responses to specific impacts (such as increased temperatures) or on reducing vulnerability by addressing underlying shortages of capability. Following the spectrum of adaptation activities delineated by the World Resources Institute (McGray, Hammill, and Bradley 2007), vulnerability-oriented efforts can overlap almost completely with traditional development practices (for example, diversification of livelihoods in flood-prone areas). Such activities generally aim at reducing poverty and addressing other fundamental shortages in capacities and assets that make people vulnerable to harm. Although most development practices do not actively take climate risks into account, they can lessen the negative impacts of climate change.

Ideally, vulnerability assessments and the evaluation of impacts should reflect a comprehensive analysis at a range of temporal and spatial scales to avoid increased vulnerability in the future (Adger, Arnell, and Tompkins 2005). "Maladaptive" strategies are those that may be successful at addressing livelihood, mitigation, or conservation objectives at a specific spatial or temporal scale but that have negative impacts at other scales of analysis. These may include strategies which (Barnett and O'Neill 2010):

- Increase emissions of greenhouse gases
- Disproportionately burden the most vulnerable
- Have high opportunity costs
- Reduce incentives to adapt
- Create or reinforce path dependency (that is, limit the choices available to stakeholders in the future)

3.2.4 Mainstreaming adaptation into development

Due to the wide array of climate change impacts that are expected across the range of development and natural resource sectors, and because the most vulnerable segments of society tend to be more dependent on both natural resources and development programs than society at large, policy makers should aim to mainstream climate change adaptation into national policies and across all sectoral programs (Huq and Burton 2003; Lemos et al. 2007; UNFCCC 2007). In fact, Agrawal (2008) argues that development interventions that do not address climate change adaptation may worsen overall well-being. An additional benefit of mainstreaming climate change adaptation into national planning is that the need for adaptation may serve as a catalyst for the development and implementation of sustainable natural resource and development policies (UNFCCC 2007).

Climate change adaptation needs to be supported by an integrated, cross-cutting policy approach for several reasons:

- Climate change impacts cut across sectors and geographic and administrative boundaries.
- Vulnerability is frequently linked to poverty and marginalization in key natural resource governance institutions.
- Climate change is projected to significantly undermine progress made toward achieving the Millennium Development Goals.
- Development choices can lead to maladaptation (for example, increase dependency on climate-sensitive resources) or be in conflict with adaptation priorities at different spatial and temporal scales.

4 INTRODUCING ECOSYSTEM-BASED ADAPTATION

The ecosystem-based adaptation (EBA) approach is gradually gaining popularity among adaptation, development, and conservation decision makers and practitioners. It has been recognized within the UNFCCC, as demonstrated by its inclusion in several adaptation proposals submitted by countries and nongovernmental organizations (NGOs) (IUCN 2008; submissions from Brazil, Costa Rica, Panama, and Sri Lanka 2009). EBA encompasses adaptation strategies that explicitly value the roles of ecosystem services in reducing societal vulnerability to climate change across sectors and scales (Vignola et al. 2009). The basic argument for EBA concerning forests is as follows (Locatelli et al. 2010a):

- Forest ecosystem services are important for a range of societal needs and are critical for reducing vulnerability to climate change.
- A reduction of these ecosystem services presents a threat to societal well-being now and increasingly 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.

EBA can be cost-effective and sustainable and can generate environmental, social, economic, and cultural benefits (CBD 2009). This is supported by a 2009 cost-benefit analysis by The Economics of Ecosystems and Biodiversity that concluded that public investment should support ecological infrastructure (forests, mangroves, wetlands, and so on) because of its contribution to adaptation to climate change (TEEB 2009).

4.1 What EBA implies for forest management

Ecosystem-based adaptation presents a number of challenges because it requires an approach that integrates inputs and roles across scales and sectors (Tompkins and Adger 2004; Folke et al. 2005; Boyd 2008). For example, EBA requires the involvement of the sectors that manage ecosystems and the sectors that benefit from ecosystems services.

Nevertheless, climate change and other human-induced land cover changes present society with increasingly complex, interdisciplinary, and urgent challenges. This will necessitate the emergence of innovative cost-benefit sharing institutions, and adaptation strategies will need to be assessed on their effectiveness and efficiency and their cross-sectoral effects. For example, a downstream hydropower plant or a drinking water facility facing problems of siltation or water quality may have an incentive to invest in upper watershed forests.

In order for EBA to be effective and sustainable, non-forest-related sectors and downstream populations or institutions would be required to support forest management. Essentially, this will involve supporting forest managers and forest user communities in their contributions to the common good (that is, benefits that will go to other sectors or downstream populations) (Glück et al. 2009). Ideally, forest management agencies and local communities that bear the costs should receive financial transfers from the other sectors (or from local and national governmental institutions planning adaptation, conservation, or development programs).

Although there is growing awareness regarding the value of forest ecosystem services, to date adaptation policies and proposed projects have tended to apply sectoral approaches and have limited the discussion on vulnerability to forest communities rather than society as a whole. Therefore, while forest-based adaptation strategies are included in National Adaptation Programmes of Action, their scope remains limited (Pramova et al. 2012b). This suggests critical gaps in or the absence of a science-policy dialogue (Locatelli et al. 2010a). In addition, it must be recognized that EBA represents a significant challenge to most national governments' modes of operation, due to cross-sectoral cooperation difficulties and the need to work across administrative boundaries as well as to each ministry's or department's interest in sourcing funding from central government treasuries.

4.2 Relevant international policy responses for ecosystem-based adaptation

From 1992, when the UNFCCC was signed in Río de Janeiro, until the recent past, most of the climate change convention's efforts were directed toward creating and implementing mitigation policies and measures. However, in 2001 the Third IPCC Assessment Report demonstrated that some degree of climate change is inevitable and that adaptation is thus a necessity (IPCC 2001).

The political interest in adaptation to climate change evolved significantly after the Seventh Conference of the Parties (COP7) of the UNFCCC, held in 2001 in Marrakesh, with the resulting Marrakesh Accord highlighting adaptation as an important area of action (UNFCCC 2002).

4.2.1 Progress toward adaptation: NAPAs, funds, and work programs

During COP7, the establishment of NAPAs for the least developed countries and the Adaptation Fund were agreed upon. The Adaptation Fund, operational in 2009, is a financial instrument under the UNFCCC and its Kyoto Protocol that aims to finance concrete adaptation projects and programs in developing countries that are parties to the protocol. The Least Developed Countries Expert Group and the Least Developed Countries Fund were established during COP7 to support the preparation and implementation of the NAPAs and the general work program for least developed countries (SBI UNFCCC, 2010).

Currently, adaptation to climate change is one of the main areas of discussion in the international climate change policy arena within the Nairobi Work Program. The Cancún Adaptation Framework established during UNFCCC COP16 in 2010 was the first global agreement on adaptation, which launched a clear working program and Adaptation Committee and defined adaptation finance as new and additional to existing aid commitments. The framework outlines the principles under which adaptation action should occur, such as transparency, stakeholder participation, gender sensitivity, consideration of vulnerable groups and ecosystems, use of indigenous knowledge and best available science, and the integration of adaptation into relevant social, economic, and environmental policies and actions (Pramova and Locatelli, 2011).

As far as the role of forests is concerned, a key point of the Cancún Adaptation Framework is the inclusion of both ecosystems and communities in its guiding principles and priorities, recognizing the need to build and sustain natural ecosystem resilience. However, there is no acknowledgment of the link between social and ecological resilience or of the potential of ecosystems such as forests to provide ecosystem services for adaptation (Pramova and Locatelli 2011).

4.2.2 Ecosystem-based approach in the negotiations

The ecosystem-based approach has been suggested as a strategy for the "integrated management of land, water and living resources that promotes sustainable development and conservation of these resources" (UNFCCC 2010, p. 36). This approach is judged to be "useful as it can take into account direct and indirect impacts as well as the effects of adaptation measures" (UNFCCC 2010, p. 36). Methods and tools from the Convention on Biological Diversity related to the ecosystem approach are also highlighted, along with the importance of ecosystem assessments for the evaluation of potential contributors to the vulnerability of communities and their livelihoods.

Several countries that are parties to the UNFCCC have submitted proposals and negotiating texts to advance the consideration and implementation of the ecosystem approach in adaptation. One such proposal is included in the negotiating text of Costa Rica that was submitted to the Ad Hoc Working Group on Long-term Cooperative Action under the Convention for its fifth session, held from March 29 to April 8, 2009.[3] Costa Rica called for the inclusion of vulnerability assessments for ecosystems, ecosystem services, and the livelihoods that depend on them as essential parts of overall risk reduction plans. The government also advocated for considering EBA in sectoral and national planning for disaster risk reduction and management, and for the evaluation of the general implications of adaptation strategies for ecosystem services on which people depend. Uruguay's submission to the Ad Hoc Working Group highlighted that it is critical for the convention to address the importance of ecosystem resilience and that adaptation strategies for the implications of climate change on ecosystems should be an essential part of the adaptation framework.[4]

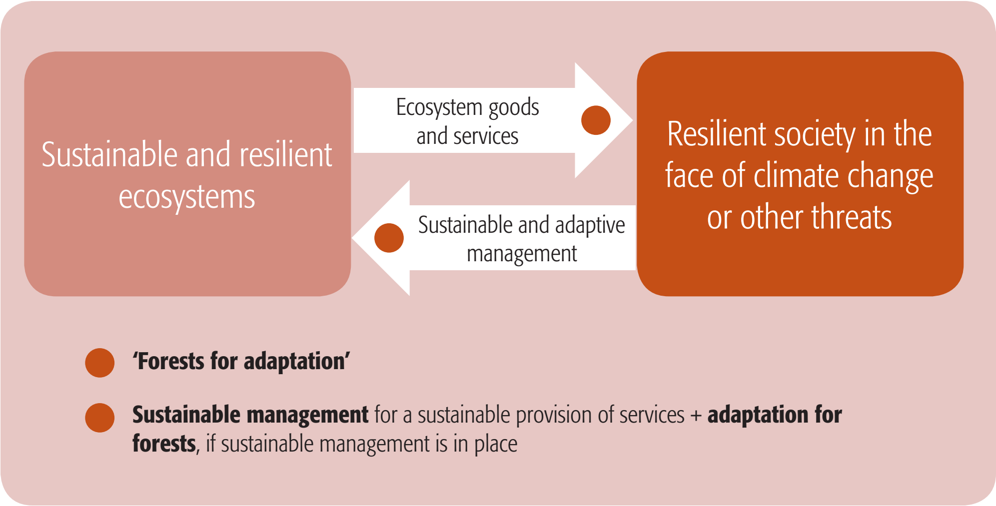
3. Draft negotiating text submitted by Costa Rica available at unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/costarica_adaptation230409.pdf (last accessed April 12, 2010).
4. Submission by Uruguay available at unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/uruguayadaptation240409.pdf (last accessed April 12, 2010).

5 FORESTS AND ADAPTATION

5.1 Understanding the links between forests and adaptation

Within the context of forestry and sectors benefiting from forest ecosystem services, climate change adaptation has two key dimensions that need to be addressed to ensure effectiveness (Locatelli et al. 2010a). First, forest ecosystems provide human societies with a wide range of 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). However, these climate change variables will also have significant impacts on forest growth, species diversity, and ecosystem function. Therefore, in order for human society to continue to benefit from forest ecosystem services, adaptation strategies must also reduce the negative climate change impacts on forests themselves. As noted in the Introduction, these two roles for adaptation can be summarized as "adaptation for forests" and "forests for adaptation" (see Figure 5).

FIGURE 5. FORESTS FOR ADAPTATION, ADAPTATION FOR FORESTS



Source: Locatelli 2011.

5.2 How ecosystem services help societies adapt

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 ecosystem services were classified by the Millennium Ecosystem Assessment (MA 2003) into the following categories:

- *Provisioning services*, also called ecosystem goods, such as non-timber forest products, food, and fuel
- *Regulating services*, such as regulation of water, climate, and erosion
- *Cultural services*, such as recreational, spiritual, and religious services
- *Supporting services* that are necessary for the production of other services, such as primary production, nutrient cycling, and soil formation

As mentioned earlier, many rural communities rely on ecosystem services and everyday resources for their coping strategies (Shackleton and Shackleton 2004). To capture the adaptation role of ecosystem services from forests, this section provides illustrations of how these services help reduce exposure, lower sensitivity, and increase adaptive capacity.

5.2.1 Ecosystem provisioning services

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 (that is, income, food security, shelter, and health) (Levy, Babu, and Hamilton 2005; Colfer, Sheil, and Kishi 2006; Colfer 2008). Goods from forests help households to diversify their livelihood portfolio. The importance of forest products as an additional source of income and nutrients is more pronounced when households are faced with climate-related variability. Provisioning services from forests assist households in the rural and agricultural sector to reduce their vulnerability to climate change.

USING FOREST RESOURCES TO COPE WITH CLIMATE VARIABILITY

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, Shackleton, and Shanley 2011). These studies underscore the critical roles that non-timber forest products play in the overall livelihood strategies of local populations. In some countries, this 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 a particularly valuable means for as a particulary recuperating the loss of productive capital following livelihood shocks.

Two studies in Tanzania document the critical roles that forest goods have in meeting the needs of poor rural households during years when harvests fail (Enfors and Gordon 2008; Paavola 2008). Indeed, during the drought years of 2005–06, 85 percent of interviewed households indicated their reliance on forest provisioning services (particularly, wild fruits and firewood), which were estimated to provide 42 percent of their total income during these years (Enfors and Gordon 2008). This made forest goods roughly as important as the combined income from short-term wage labor, remittances, and off-farm employment. It should also be mentioned that because charcoal production was illegal, based on qualitative interview data, these estimates were judged to vastly underrepresent the critical roles of forest products overall. 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 McCusker 2010).

Forest products are an important safety net 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).

INTENSIFYING FOREST/TREE MANAGEMENT TO REDUCE VULNERABILITY

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 the 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 NGOs encouraged local communities to develop local 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 (banning logging within 50 meters of the outer margin) (Prasetiamartati et al. 2008).

ELITE CAPTURE OF INCOME FROM VALUABLE FOREST PRODUCTS

Research by numerous authors has highlighted how external interests or local elites have a tendency to capture a disproportionate share of the benefits from the sale of NTFPs once their value is recognized or infrastructural development facilitates traders' access to previously remote communities (Pandey et al. 2007). To illustrate, Dove (1993) documented the Indonesian examples of latex and rattan, where internal or external elites captured benefits from NTFPs once it became apparent that money could be made from them. Similarly, Nkem et al. (2010) documented how the distribution of market revenue from the sale of many NTFPs in the Congo basin left rural stakeholder with a minimal share of retail forest product value, while wholesalers and retailers reaped most of the benefits. In the case of the marketing of fish from forested areas of the Congo basin, Russell et al. (2007a, 2007b) found this to be caused by a combination of traders' and elites' networks in urban markets and their greater access to capital, which enabled them to overcome the barriers of rent-seeking behavior by civil servants. Therefore, it must be understood that markets may increase the value of the commodity, but it seems their contribution to the adaptation of local communities may be limited, as the distribution of benefits is unequal. Markets should be regarded as complementing, rather than substituting for, the direct roles of forests in adaptation.

5.2.2 Ecosystem regulating services

Though more difficult to measure, forest regulating services are critical to society. All forest types contribute to microclimate regulation and stabilization, sediment retention, and nutrient cycling - all important services for the resilience of 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, Brown, and Tompkins 2005), and reducing temperatures during heat waves (Gill et al. 2007). In Central America, for example, climate change predictions of increased rainfall intensity are causing concern about erosion and siltation among hydroelectricity companies, and they are considering upstream watershed forest conservation as a critical measure to adapt to climate change (Vignola and Calvo 2008).

The discussion in this section 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, riverine and floodplain forests, agroforested landscapes, and coastal forest and wetlands.

RESTORING LAND USING TREES TO INCREASE ADAPTIVE CAPACITY

In Kenya, the Regional Development Authorities are implementing catchment conservation programs covering vast areas in the country to promote practices that, among other things, address soil erosion and water loss. One of their interesting approaches was *fanya juu* terracing and the cutting of drains that was adopted in dry parts of the Machakos, Majueni, and Kitui districts.[5] Because of their success in areas that otherwise would be bare lands, these practices are spreading to other areas of the country. In Machakos, for instance, crop yields have increased by 50 percent (or by 400 kilograms per hectare) through the use of *fanya juu* terraces.

In Mali and Niger, for the past 30 years the loss of natural vegetation reduced the arid zone ecosystems' resilience to recurrent droughts. As a consequence, local people face famine, poverty, and migration. In an already drought-afflicted region, additional climatic stresses are expected to be detrimental to food security and development. International donor assistance has been provided to these countries to finance reforestation of more than 23,000 hectares of *Acacia senegalensis*, a species native to the African Sahel, on communal degraded land throughout Mali and Niger. The planting of this native species is expected to restore habitat for native fauna and is projected to sequester approximately 0.3 metric tons of CO_2 equivalents (Mt CO_2e) by 2017 and 0.8 Mt CO_2e by 2035 in Mali, plus 0.24 Mt CO_2e by 2012 and about 0.82 Mt CO_2e by 2017 in Niger. The rehabilitation of degraded land improves soil fertility, creates

5. *Fanya juu* terraces are constructed by digging a contour trench and moving the soil to the upper part of the trench in order to form an embankment on which to plant fruit trees, Napier grass, or something else. The trench traps and holds water that is gradually released to the farmland. The labor required for construction is estimated at 150–350 person days/hectare for terraces and cutoff drains. The cost of these structures is approximately $60–460/hectare.

jobs, and increases local incomes through sales of high-quality Arabic gum and payments from carbon emission reductions (Tahia 2010).

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 are confounded by other studies, however. A meta-analysis of watershed services, provided by limited studies of humid natural forests versus planted forests in Central America, indicates that planting does not provide these 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, studies on soil erosion find that soil coverage (understory vegetation and litter layer) may have more influence on the rate of soil erosion 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 ecosystem services are at times overrepresented in the development of payment for ecosystem services 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 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 ecosystem services in the short or medium term (Calder 2002).

In Costa Rica, efforts to reduce sedimentation of a hydropower dam, however, found that using reforestation or soil conservation measures in erosion hotspots made economic sense. Erosion affects hydropower dams by increasing the costs for companies to extend the life span of the dams. It also affects the life span of the hydropower dams themselves. In the Birris watershed of Costa Rica, the life span of a hydropower dam depends on the quality of water reaching it, which is determined by sediment loads flowing down the watershed. Indeed, each year up to 1.5 million tons of sediment loads are removed from the dams to ensure the longest possible life span. More than $2 million is spent to partially remove these sediments and to produce energy by alternative sources during this operation. A study exploring different measures for controlling soil erosion and continuing with business as usual in the Birris watershed found that reforestation or soil conservation practices in high-risk areas for erosion brought about significant reduction in erosion. However, the reforestation could be done at a lower cost and offered greater net benefits (Aylward, Hartwell, and Zapata n.d.).[6]

In Kenya, a rapid assessment of the impact of climate change on hydropower generation under minimum and maximum climate change projections in the Tana river basin showed that the impact of climate change without adaptation strategies ranges from a positive $2 million to a cost of $66 million for the hydropower, irrigation, and drinking water sectors. However, when the costs and benefits of various adaptation strategies are accounted for, the measures result in positive outcomes ranging from $11 million to $29 million for the low and high climate change projections, respectively. The study compared adoption of infrastructure-based and ecosystem-based adaptation measures and found that the EBA measures were profitable only if the climate trends in the direction of more significant temperature changes (Droogers et al. 2009).

RIVERINE AND 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 river banks slow 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 to 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).

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,

6. It should be noted that while the study pointed to the optimal approach, the preference of the stakeholders was not for the best alternative from an erosion-control perspective (that is, reforestation of high-risk areas). Stakeholders preferred adopting soil conservation practices in high-risk areas (a mix of activities, from increasing tree cover to improved soil management practices in agricultural plots), which brought a convergence of benefits to hydropower and farmers. This approach avoided the large cost to target soil conservation all over the watershed yet significantly improved the provision of on-site and off-site benefits of erosion control. At the same time, the approach allowed farmers to avoid drastic land use change and maintain their agricultural livelihoods, thereby preserving the economic, social, and cultural paradigms of local communities.

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), who 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.

COASTAL FORESTS AND WETLANDS

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 (Alongi 2007; Badola and Hussain 2005; Das and Vincent 2009; Danielson et al. 2005; 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 (2005) compared the impacts of cyclones in 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). Apparently, 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 maintaining or restoring 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 had 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).

5.3 Why we should take adaptation for forests seriously

The impacts of climate change on forests will vary widely between countries and regions, and these impacts will be compounded by other society-induced drivers of change (for example, land use change, pollution, and overexploitation of resources) (Locatelli et al. 2010a). Some change-inducing factors of exposure and of forest sensitivity are presented in Figure 6.

FIGURE 6. COMPONENTS OF THE EXPOSURE AND SENSITIVITY OF FOREST ECOSYSTEMS

Exposure

Climate change and variability
Increase in temperature, changes in precipitation, changes in seasonal patterns, hurricanes and storms
Increase in Co_2 levels
Sea level rise
Other drivers
Land use change, landscape fragmentation, resource exploitation, pollution

Sensitivity

Changes in **tree-level processes**
e.g., productivity
Changes in **species distribution**
Changes in **site conditions**
e.g., soil condition
Changes in **stand structure**
e.g., density, height
Changes in **disturbance regimes**
e.g., fires, pests, and disease

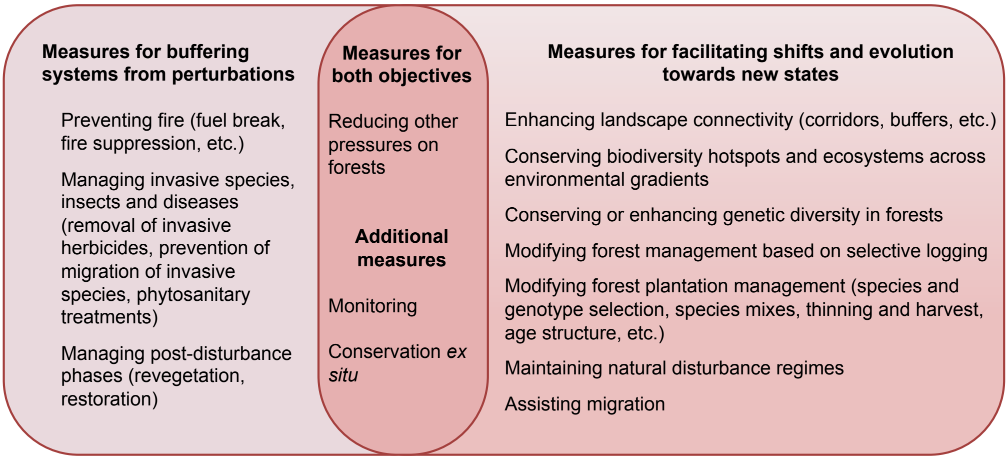
Although the adaptive capacity of forests remains uncertain (Julius and West 2008), many scientists are concerned that this innate capacity will be insufficient for forests to adapt to unprecedented rates of climatic changes (Gitay et al. 2002; Seppälä, Buck, and Katila 2009). The impacts of climate variability and change on the ecosystem structure and functioning of tropical forests and on carbon cycling have already been documented (Root et al. 2003; Fearnside 2004; Malhi and Phillips 2004). The impacts on three major forest types are as follows:

- **Humid tropical forests** in Indonesia and Brazil are experiencing increased droughts and frequencies of forest fire, and there is some concern that this might contribute to a large-scale conversion of tropical rainforest to savanna in the Amazon (Barlow and Peres 2004; Murdiyarso and Lebel 2007; Cox et al. 2004; Scholze et al. 2006; Nepstad et al. 2008). Adaptive capacity (through migration and colonization of new areas) will be diminished through forest fragmentation and the spread of invasive exotic vegetation (Nepstad et al. 2008; Fischlin et al. 2007).

- **Tropical dry forests** are particularly sensitive to small changes in precipitation because they expose the landscape to greater desiccation and increase the risk from forest fires (Hulme 2005; Miles 2006; Mwakifwamba and Mwakasonda 2001; Enquist 2002).
- **Tropical mangrove forests** are underappreciated and have been severely reduced due to conversion of coastal zones for tourism, infrastructure, and aquaculture development. To survive the predicted sea level rises, mangroves require increased amounts of sediment accumulation from inland watersheds in order to counteract coastal erosion, or they need space to migrate inland. Due to coastal development, the space for migration is limited, and sea levels are expected to rise at about twice the rate of sediment accumulation (Hansen et al. 2003).

Two broad approaches are possible for adapting forests: either buffering the system from climate change impacts by increasing its resistance or facilitating a shift or an evolution of the system toward a new state that meets altered conditions (see Figure 7). However, measures that attempt to keep forests in their current state may be effective only over the short term and are likely to be associated with high costs due to the intensive management required for implementation, frequently leading to increased vulnerability in the long term. Consequently, these measures are recommended for only high-value forests (for example, high-priority conservation forests for biodiversity) or for forests with low sensitivity to climate change (Millar, Stephenson, and Stephens 2007). Of critical utility are actions that may contribute to both buffering and long-term resilience, such as reducing forest conversion, fragmentation, and degradation (Noss 2001; Hansen et al. 2003; Malhi et al. 2008). In many tropical ecosystems, the urgency of addressing non-climatic threats far outweighs the climatic ones (Markham 1996). Uncertainties about climate change and forest vulnerability highlight the need for flexible and diverse approaches that permit changes in the future (Millar, Stephenson, and Stephens 2007).

FIGURE 7. EXAMPLES OF TECHNICAL MEASURES FOR FOREST ADAPTATION



Source: Locatelli et al. 2008.

6 CONCLUSIONS AND WAY FORWARD

Future climate change depends on many uncertain factors. Declining productivity, declining water availability, and increased risk of disasters are the trends that existing climate models point to at a very macro level. For many developing countries, the immediate need is to be able to adapt to these imminent and ongoing changes. This has to happen at a time when public financial resources are limited and the most affected households are not well positioned to adapt on their own.

6.1 Forests can help societies adapt to climate variability and change

Climate change impacts are already threatening to stall and even reverse development trajectories in many developing countries, leading to an urgent need for efficient and sustainable adaptation. Currently, the net present value of climate change impacts in the absence of adaptation measures is estimated at $1,240 trillion (CBD 2010), while the UNFCCC (2007) estimates the cost of adaptation in agriculture, coastal zone, forestry, fisheries, health, infrastructure, and water supply sectors combined could reach $44–166 billion per year by 2030 for the world as a whole and $28–67 billion for developing countries. While the estimates of costs and benefits of adaptation are wide-ranging, they all point to the urgency of adaptation. They also point to the need to think through how we do adaptation and to do it in a way that yields multiple gains.

A secure flow of forest ecosystem goods and services has the potential to significantly aid societal adaptation to climate change. Mangroves can protect coastal areas against storms and waves, which are predicted to become even more intense with climate change and climate-induced sea level rise. Forest products can provide safety nets to local communities when climate variability causes crop failures, and urban forests can reduce temperatures during heat waves.

Forest ecosystems not only have the potential to reduce the vulnerability of communities to climate vagaries by protecting settlements and enhancing livelihoods and food security, they can also play an important role in the adaptation of national economic sectors. The hydroelectric sectors of Costa Rica and Nicaragua, for example, which are crucial for the sustainable development of the two countries, are directly dependent on such hydrological forest ecosystem services as the regulation of water quantity and the reduction in soil erosion and sedimentation (Locatelli et al. 2010b).

Conversely, degraded forests and insecure flows of forest ecosystem services can make communities and sectors more vulnerable to climate variability and change, and lead to increased adaptation costs. For instance, extensive deforestation around Malaysia's capital, Kuala Lumpur, coupled with recurring dry conditions led to strict water rationing in 1998 and ultimately to costly imports of water (CBD 2010). In Haiti, Hurricane Jeanne caused an estimated 3,000 deaths from torrential rainfall flooding, due in part to the country's highly deforested and degraded watersheds (World Bank 2009).

Ultimately, the use of forests can foster an integrated approach to adaptation and mitigation, and maximize the benefits achieved in addressing climate change (Locatelli et al. 2011). For example, agroforestry activities eligible under the Clean Development Mechanism can also be managed for the reduction of community vulnerability through erosion control and crop protection. Likewise, mechanisms such as REDD+ could—depending on their design and implementation—contribute to adaptation by improving local livelihoods, strengthening local institutions, and conserving ecosystem services (Angelsen et al. 2012).

6.2 Using forests for adaptation requires a supportive institutional context

Mainstreaming forests into adaptation policies requires cross-scale and cross-sectoral approaches, as ecosystem benefits and management costs generally occur in different locations and affect different sectors of society. However, the sectors that depend on forest ecosystem services rarely have an incentive to get involved in forest-based adaptation, and this results in missed opportunities for intersectoral planning and financing of forest conservation, restoration, and sustainable management. Hydropower or drinking water facilities facing problems of siltation or water quality, for example, could be encouraged to invest in upstream forest management instead of opting for more costly measures, such as technical filtration and treatment or infrastructure repairs.

Policy makers should create an environment that links ecosystem managers with vulnerable sectors that benefit from ecosystem services. Incentive-based policy instruments like payments for ecosystem services can be one way to achieve positive results, contributing to the adaptation of both forests and users of forest ecosystem services.

Policies should also encourage strategies that aid the adaptation of the forest ecosystems themselves in order to ensure the role of these ecosystems for social adaptation. Forest ecosystem resilience is a key issue that needs to be considered across scales because it can be undermined by a diverse range of anthropogenic, environmental, and climatic factors and because forests themselves are highly vulnerable to climate change.

Adaptation measures for forests can aim to buffer ecosystems from disruptions by increasing their resistance and resilience. They can also focus on facilitating a forest ecosystem shift toward a new desired state while maintaining forests' structure, function, and ability to provide critical services. Adaptive management that responds to environmental and other feedback is crucial for forest ecosystems to adapt effectively to climate change. Adaptive management is also important for social adaptation, because climate change is highly likely to alter the form, scale, location, and distribution of forest ecosystem services.

On national and subnational levels, it is crucial to map, model, and evaluate the multiple flows of forest ecosystem goods and services to the diverse users who depend on them. The analysis of important ecosystem services and identification of stakeholders can provide a better understanding of vulnerability as well as important clues on the potential winners and losers of specific changes in socioecological systems due to climate change. Such exercises can also help identify priority areas for forest conservation and restoration, and can develop spatially targeted policies for forest management involving key users of ecosystem services.

It is important to make sure that forest-based adaptation strategies generate benefits in the short term that help cope with climate variability. Immediate benefits can help minimize the threat of forests being negatively affected by short-term and shortsighted coping strategies. This also points to the urgency of providing evidence to governments of these immediate benefits (or the possible costs of forest degradation) and the need to complement that by putting in place the institutional fabric and technical support for proactive adaptation strategies and cross-sectoral coordination.

Effective local institutions, as well as national and subnational institutions, are central in facilitating the use of trees and forests in adaptation and promoting an intersectoral approach. The promotion of forest-based adaptation will therefore have to be accompanied by efforts to promote better governance (for example, secure tenure rights and local access to forests' goods and services). This will require using innovative and practical approaches and institutional measures to foster tree- and forest-based adaptation.

It should be made clear that forest adaptation strategies should not be implemented at the expense of forest-dependent people through command-and-control measures and that there is much that can yet be learned from people's existing livelihood strategies and coping mechanisms. Adaptation strategies should build on local knowledge, seeking to understand how policy and socioeconomic incentives interact with environmental and climatic conditions to shape locally attuned livelihood strategies. And they should aim to integrate local coping needs with broader conservation and climate change adaptation objectives.

In the climate change arena, forests are seen as a solution to the mitigation agenda. Evidence presented in this report and elsewhere underscores the potential role of forests in enhancing resilience to climate change. The challenge ahead is to balance the priorities of mitigation and adaptation in the solutions developed for addressing climate change. Ecosystem-based approaches that involve forests and that link adaptation and mitigation are seen as a key way forward. These adaptation-based mitigation solutions involve using forests to implement an integrated approach to climate change action by bringing together efforts to increase resilience and efforts to reduce the pace of climate change. Adaptation-based mitigation is seen by many as a no-regrets measure. Achieving it will require managing forests to ensure they are resilient to climate change while using trees and forests to enhance resilience in other sectors.

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FOREST ECOSYSTEMS PROVIDE A WIDE RANGE OF SERVICES THAT REDUCE HOUSEHOLDS' VULNERABILITY TO CLIMATE CHANGE, SUCH AS INCOME, FOOD, BIOMASS, EROSION MITIGATION AND STORM FLOW REGULATION. FORESTS CAN, THEREFORE, BE OF VALUE IN THE ADAPTATION STRATEGIES OF OTHER SECTORS. INTEGRATING FORESTS INTO ADAPTATION STRATEGIES THAT EXPLICITLY VALUE FOREST ECOSYSTEM SERVICES IN ADAPTATION TO CLIMATE CHANGE ACROSS SECTORS AND SCALES AND HELPS TACKLE LAND USE CHANGE THAT OFTEN COMPOUNDS THE IMPACTS OF CLIMATE CHANGE.

MAINSTREAMING FORESTS INTO THE ADAPTATION POLICIES OF OTHER SECTORS REQUIRES CROSS-SCALE (LOCAL TO NATIONAL, AND IDEALLY INTERNATIONAL) AND CROSS-SECTORAL APPROACHES. A GREATER UNDERSTANDING OF HOW FOREST ECOSYSTEMS REDUCE OTHER SECTORS' VULNERABILITY TO CLIMATE CHANGE, AS WELL AS HOW THE MANAGEMENT OF FOREST ECOSYSTEMS IN CERTAIN LANDSCAPES CAN ASSIST WITH ADAPTATION OF FOREST SYSTEMS, IN NEEDED IN ORDER TO ESTABLISH SUCH APPROACHES. THIS REPORT PROVIDES A REVIEW OF WHAT IS KNOWN ABOUT FORESTS AND THEIR ROLE IN CLIMATE CHANGE ADAPTATION TO HELP INFORM SUCH APPROACHES.

PROFOR

PROGRAM ON FORESTS (PROFOR)

THE WORLD BANK
1818 H ST NW
WASHINGTON DC 20433 USA

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

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