B3 Climate-smart forestry

Overview

This module investigates the role of forests and trees in climate-smart agriculture. It takes into consideration the ecosystem services and goods that forest provide and the importance of forests to the food security of forest-dependent people. Chapter B3-1 looks at the relationship between climate change and forests; the practice of sustainable forest management; the risks posed by climate change to forests and forest-dependent people; the measures needed to adapt forests to climate change; the role of forests in mitigating climate change; and the synergies and trade-offs involved in managing forests to mitigate and adapt to climate change. Chapter B3-2 examines ways of enhancing the contributions that sustainable forest and tree management can make to food security and livelihoods; reducing the vulnerability and increasing the resilience of forests and people to climate change; and maximizing the sector’s role in mitigating climate change and maintaining food security. Chapter B3-3 looks at management approaches for implementing climate-smart actions in the forest sector. Chapter B3-4 deals with policy approaches.

In general, the text in this module refers to forests and various configurations of trees outside forests. The blanket term 'forests' is used to cover both of these concepts. Climate-smart agriculture as it applies to forests and trees, and the use and management of these resources is referred to as 'climate-smart forestry'. Climate-smart forestry requires the consistent and widespread application of the principles of sustainable forest management. These principles provide the foundation for mitigating and adapting to climate change in the forest sector.

Key messages

- The impacts of climate change on forest goods and services will have far-reaching social and economic consequences for forest-dependent people, particularly the forest-dependent poor. Adaptation and mitigation measures must go beyond isolated technical solutions and address the broader human and institutional dimensions of the climate change.

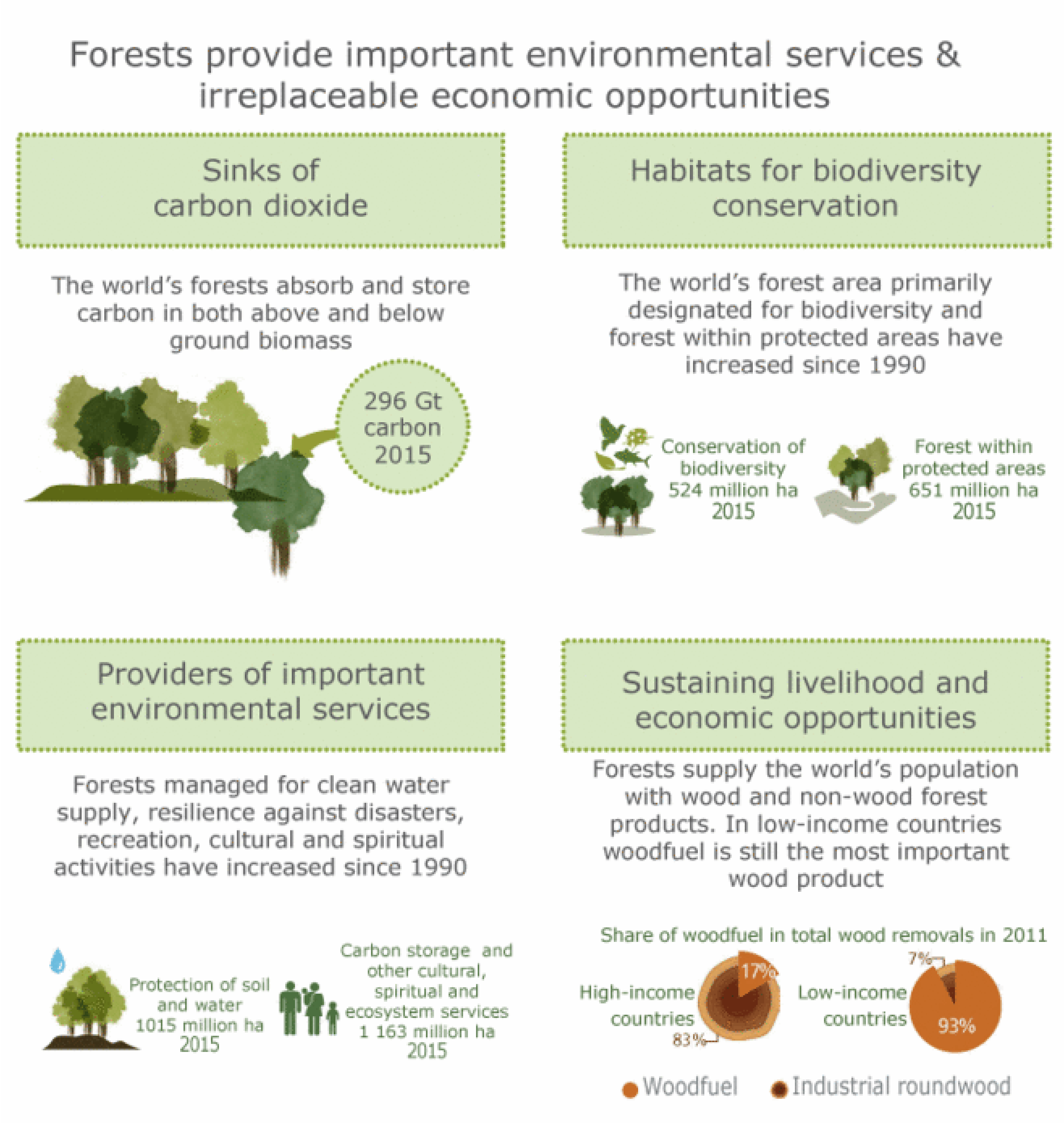
- Sustainable forest management is essential for reducing the vulnerability of forests to climate change. It provides a fundamental foundation for climate change mitigation and adaptation, and contributes to food security.
- Mainstreaming climate change into forest policies and practices through sustainable forest management will require trade-offs between climate change adaptation and mitigation, food security, and other forest management objectives, but it will also capture the synergies that exist among these different goals.
- Efforts to make the transition to climate-smart forestry are needed at all levels (household, business, community, national, regional and global) and all time scales. They should involve all stakeholders and be tailored to local circumstances.
- Climate-smart forestry will require adaptation and mitigation actions that target the most vulnerable communities and stakeholders (e.g. women, the elderly and indigenous peoples) and encourage their involvement.
- Climate-smart forestry should focus on the most vulnerable forest systems (e.g. dryland, mountain and coastal forests) and the most efficient and cost-effective mitigation options. It should capitalize on adaptation-mitigation synergies.
- Robust monitoring involving all stakeholders is essential for enabling the adaptive management of forests and trees in the face of climate change and ensuring the effectiveness of forest-based mitigation actions.

Forests and climate change

Forests and trees deliver important ecosystem goods and services (Figure B3.1). The provide a continuing supply of timber, pulp, bioenergy, water, food and medicines. They also offer opportunities for recreation, and play prominent roles in many cultural traditions. Forests are habitat for a large share of the Earth's plant and animal species. Tropical forests, in particular, are biodiversity hotspots (Gibson *et al*., 2011). Forests are crucial for sustainable agricultural development because of the role they play in the water and carbon cycles, soil conservation, pest management, the amelioration of local climates and the maintenance of habitats for pollinators.

There is a close interrelationship between climate change and forests. Air temperature, solar radiation, rainfall and concentrations of carbon dioxide in the atmosphere are major factors in forest productivity and forest dynamics. Forests, in turn, affect climate by removing and releasing large amounts of atmospheric carbon, absorbing or reflecting solar radiation (albedo), cooling through evapotranspiration and producing cloud-forming aerosols (Arneth *et al*., 2010; Pielke *et al*., 2011).

Figure B3.1. The ecosystem services and economic opportunities provided by forests



B3-1.1 The impacts of climate change on forests - the need for sustainable forest management

Implementing forest-related initiatives to mitigate and adapt to climate change on the ground requires a comprehensive approach supported by sound policies, and appropriate legislative and governance frameworks. Sustainable forest management is a universally accepted concept that guides forest policies and practices worldwide and constitutes an overarching approach to forest management. At the national or subnational level, the implementation of sustainable forest management requires enabling policies, laws and institutions. On the ground, it involves the application of sound management practices based on good science and traditional knowledge. Sustainable forest management can be applied in all types of forest, regardless of the forest management objectives (e.g. production, conservation, protection and multiple use). In 2007, the United Nations General Assembly adopted language that describes the sustainable forest management concept and lists the elements it encompasses (Box B3.1).

Box B3.1 Sustainable forest management

In Resolution 62/98, the United Nations describes sustainable forest management as a dynamic and evolving concept that "aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations". It recognizes seven thematic elements of sustainable forest management:

1. extent of forest resources;
2. forest biodiversity;
3. forest health and vitality;
4. productive functions of forest resources;
5. protective functions of forest resources;
6. socio-economic functions of forests; and
7. legal, policy and institutional framework.

Efforts worldwide to make progress towards sustainable forest management have provided a wealth of knowledge, experiences, best-practice guidance, tools, mechanisms and partnerships that can support efforts to meet the challenges posed by climate change. Using sustainable forest management as an overall framework helps ensure that adaptation and mitigation measures are carried out in synergy with other forest management objectives and take into account the economic, social and environmental value of forests. Mainstreaming climate change into forest policies and practices will allow for the identification and management of synergies and trade-offs with other forest management objectives.

Adaptive management

Adaptive management is a dynamic approach to forest management in which changing conditions are monitored and practices modified accordingly. It explicitly addresses complex and uncertain situations and is widely seen as part of an appropriate overall response to climate change, including in the forest sector.

Landscape approach

As integral parts of broader landscapes, forests and trees contribute to ensuring the stability and vitality of ecosystems and meeting societal needs. Integrated approaches to landscape management (addressed in module A3) can increase synergies among multiple land-use objectives. By considering the perspectives, needs and interests of all stakeholders, including local communities and individual land users, landscape approaches can be instrumental in developing sustainable strategies for land use and related livelihoods. Broad stakeholder dialogue is especially important when making changes to the way land is used and managed in the landscape. For example, addressing the drivers of deforestation, which are associated with factors well beyond the forests themselves, requires following a cross-sectoral landscape approach and reaching a consensus among multiple stakeholders. Some impacts of climate change (e.g. an increased risk of fire or pests) may require managers to look beyond their own management units and integrate their management approaches with those of other stakeholders living in similar landscapes. Adopting a landscape approach can help in identifying and implementing forest-based climate change adaptation and mitigation measures that lead to optimal economic, social and environmental outcomes.

Partnerships and participatory approaches

Given the many and diverse interests in forests, it is crucial that all stakeholders are involved in forest management. Partnerships and participatory approaches can operate at a range of levels, from the national to local level. They may involve state and local authorities, forest extension agencies, forest-dependent communities, non-governmental organizations, private-sector entities, research and academic organizations, and forest managers.

Indigenous knowledge

Local and indigenous communities have managed forests and associated landscapes over centuries or even millennia. They have done this in ways that have sustained their livelihoods and cultures without jeopardizing the capacity of ecosystems to provide a continuous supply of goods and services. The knowledge, innovations and practices of these communities have evolved through experiences gained from their encounters with changes in environmental, economic, political and social conditions (Parrotta, Youn and Camacho, 2016).

Typically, traditional knowledge is conveyed orally from generation to generation through stories, songs, folklore and proverbs, and through the direct training of youth by elders. Traditional knowledge, supported by and embodied in local languages, cultural values, beliefs, rituals, laws and governance systems, has created a diverse set of natural resource management practices that sustain food security, health and traditions (Berkes, 2008). Complex forest management practices based on traditional knowledge, including natural forest management, shifting cultivation and agroforestry systems, continue to meet the material and non-material needs of societies without putting the biodiversity and functional integrity of forests and associated ecosystems at risk.

B3-1.2 The impacts of climate change on forests - the need for adaptation

The rate of climate change varies depending on the geographical scale under consideration. The extent of change generally increases with the distance from the equator. Locally, the rates and directions of climate change are affected by the topography and proximity to large water bodies. Forest species and forest-dependent people differ in their resistance (i.e. their ability to remain unchanged in the face of disturbances) and resilience (i.e. their capacity to absorb disturbances and reorganize during change, so as to retain essentially the same functions, structure and identity)[ii] to climate change and in their adaptive capacity. To cope with climate change, species will need to adapt to the changed conditions or migrate to areas with suitable conditions for survival. The ability of species to migrate will depend on their capacity to disperse and the existence of physical connections to suitable habitats. The risks of species losses and ecosystem disruption in forests will vary geographically and over time. Neither the climate nor species respond linearly to changing conditions; they tend to react abruptly when certain thresholds or tipping points are reached.

Communities differ in the extent to which they are vulnerable to climate change. Among the most vulnerable communities are those that are already struggling with poverty, have limited options for gaining employment or earning income, and depend directly on rainfed agriculture or forests for their livelihoods.

In the forest sector, adaptation encompasses changes in management practices and interventions designed to decrease the vulnerability of both forests and forest communities to climate change. See [Climate Change Guidelines for Forest Managers] for specific adaptation measures in forestry.

Forests and climate change adaptation are connected in two main ways (Locatelli *et al*., 2010). First, forests contribute to adaptation by providing ecosystem services that reduce the vulnerability of local communities and broader societies to climate change. For example, the supply of forest goods tends to be more climate-resilient than the supply of traditional agriculture crops. When disaster strikes or crops fail, forests act as safety nets that can provide the affected communities with food and income. Forests also provide ecosystem services that are essential for livelihoods, food security, environmental sustainability and national development. Climate change jeopardizes the delivery of these goods and ecosystem services. The second way that forests are linked to climate change adaptation relates to the effects climate change will have on forests and the measures that are needed to reduce the negative impacts and maintain forest ecosystem functions. Choices of adaptation measures for a given forest will be determined by the expected impacts of climate change, the management objectives (which may shift in light of climate change), management history, and a range of other factors. All management actions to adapt a forest to climate change must be consistent with sustainable forest management. Policies, laws and governance frameworks must be sufficiently flexible to facilitate and support the actions taken to adapt forests to climate change (i.e. adaptive management). See also chapter B8-5 on adaptation options for forest genetic resources.

Biophysical impacts

Forest area

The area covered by forests is likely to change as the climate changes. There will also likely be shifts in forest types due to changing temperatures and precipitation regimes. Forest area is expected to expand in the temperate zone and contract in the boreal and tropical regions, and in mountains. Similar changes have occurred in past geological eras due to natural changes in climate, but in the present era it will be difficult to isolate climate change from the other factors that are affecting the range of forest area (Lucier *et al*., 2009).

Planted forests and natural regeneration have increased the forest area in China, the United States of America, many countries in Europe, and some countries in Latin America and the Caribbean (e.g. Chile, Costa Rica, Cuba and Uruguay) (FAO, 2010). On the other hand, some countries in Africa, Asia and the Pacific, and Latin America continue to experience deforestation and forest degradation, due mainly to the conversion of forest land to small- and large-scale crop and livestock production. Deforestation in the boreal forests of Siberia in the Russian Federation is due mainly to forest fires (FAO, 2009).

Boreal forests are expected to move north due to climate change. Temperate forests are also expected to increase their area to the north but to a greater extent than boreal forests, which will reduce the total area of boreal forests (Burton *et al*., 2010).

It is expected that the impacts of climate change, land-use conversion and unsustainable land-use practices will interact with each other. Changes in water availability will be a key factor in the survival and growth of many forest species, although the response to prolonged droughts will vary among species and also among varieties of the same species (Lucier *et al*., 2009). Climate change will increase the risk of frequent and more intense fires, especially in areas where it leads to lower precipitation or longer dry periods, as in boreal forests (Burton *et al*., 2010), and forests in Mediterranean and subtropical regions (Fischlin *et al*., 2009), and areas where traditional fire-based land-clearing practices are used, as in the Amazon (Aragão *et al*., 2008; Nepstad *et al*., 2008).

Health and vitality

Climate change may have profound impacts on the health and vitality of the world's forests. Forest health and vitality are determined by considering a range of factors (e.g. age, structure, composition, function, vigour, the presence of unusual levels of insects or disease, and resilience to disturbance). It is important ot recognize that the perception and interpretation of forest health and vitality is influenced by individual and cultural viewpoints, land management objectives, spatial and temporal scales, and the appearance of the forest at a particular point in time (Helms, 1998).

In some cases, vitality may increase due to a combination of carbon dioxide fertilization and a more favourable climate. In most cases, however, increasing temperatures will favour the growth of insect populations that are detrimental to forest health (Lucier *et al*., 2009), especially in forests dominated by a few tree species or where insect populations are sensitive to seasonal shifts in temperature or moisture levels (Box B3.2).

Box B3.2 Climate change could favour the spread of forest insect pests

The spread of the mountain pine beetle (*Dendroctonus ponderosae*) in boreal forests has largely been attributed to the absence of consistently low temperatures over long periods, which have allowed an existing outbreak to spread across montane areas and into colder boreal forests (Burton *et al*., 2010). An increase in infestations of root and bud rots is expected in Finland's coniferous forests due a virulent fungus, *Heterobasidion parviporum*, whose spread is favoured by longer harvesting periods, increased storm damage and a longer spore-production season (Burton *et al*., 2010). In the tropics, increased warming accelerates the life cycle of many insect pests, and increased fire damage makes trees more susceptible to insect attacks, which in turn speeds up the life cycle of these pests (Lucier *et al*., 2009).

Biodiversity

Most tree species have a climatic range within which they grow best, are competitive with other plant species, can adapt to environmental change, and respond to increased insect attacks, disease, and adverse environmental conditions and anthropogenic influences. Some species will adapt better than others to changing conditions, which will lead to changes in the composition of forests rather than in geographic shifts in forest types (Breshears *et al*., 2008) (Box B3.3). In general, tree species are likely to move to higher latitudes or altitudes due to global warming (Rosenzweig *et al*., 2007; Breshears *et al*., 2008).

Box B3.3. Phenological change in tree species

In their revision of the impacts of climate change on forests, Lucier *et al*. (2009) reported observed phenological changes (i.e. changes in the events in the life cycle of a species) in a number of tree species. The highest number of changes and the most significant changes were noted at higher latitudes. Commonly observed effects were changes in the timing of flowering and bud break, which can affect productivity and carbon sequestration potential. Phenological changes in oak (Bauer *et al*., 2010), apple and pear (Blanke and Kunz, 2009), and 29 Mediterranean species (Gordo and Sanz, 2010) did not affect ecosystem processes. Changes were easier to predict in insect-pollinated species than in wind-pollinated species. In tropical systems, phenological changes may affect ecological processes, such as pollination, flowering and fruit setting, to a greater extent. This is because species interactions may be more complex and involve more species and because seasonality is not as clearly marked (see also B3 Annex 1).

Productivity

The impact of climate change on forest productivity (i.e. the potential of a particular forest stand to produce above-ground wood volume) varies according to geographic area, species, stand composition, tree age, soils (particularly their capacity to retain water), the effects of carbon dioxide and nitrogen fertilization, and interactions between these factors (Girardin *et al*., 2008; LeBauer and Treseder, 2008; McMillan *et al.*, 2008; Ollinger *et al*., 2008; Phillips *et al*., 2008; Reich and Oleksyn, 2008; Saigusa *et al*., 2008; Clark *et al*., 2003). Some changes may be temporary, with conditions reverting back to their previous status once saturation levels are reached. This is projected to be the case for water availability, where a reduction in availability generally reduces plant growth. In areas of water surplus, however, there may be an initial increase in growth if there is less waterlogging. Similar reactions have been noted for carbon dioxide (Ollinger *et al*., 2008; Clark *et al*., 2003), nitrogen fertilization (LeBauer and Treseder, 2008), and increased temperatures (Reich and Oleksyn, 2008).

In general, in most forest areas, productivity has been found to increase with higher temperature, which is probably due to carbon dioxide fertilization. In contrast to temperate areas, however, increases in productivity in tropical forests will be temporary and will decline when carbon dioxide saturation is reached. Some studies have already reported decreasing growth rates in tropical forests (Feeley *et al*., 2007; Clark *et al*., 2003).

Water deficits over extended periods have been shown to decrease productivity (Malhi *et al*., 2008) and may be the cause of the reported productivity declines in the studies cited above. Based on palaeontological evidence, Some authors have argued that reduced productivity may not result in the forest dieback, which is often mentioned in connection with expected changes in the Amazon due to climate change (Mayle and Power, 2008). Natural disturbances often decrease forest area and, through the damage they cause to standing trees, they may also decrease productivity (Chakraborty *et al*., 2008; Jepsen *et al*., 2008; Kurz *et al.*, 2008; Nepstad *et al*., 2008).

Soil and water protection

It has long been recognized that forests contribute to water and soil protection. In several countries, recognition of this fact has translated into schemes to pay landowners, or offer them other incentives, for providing these ecosystem services (Postel and Thompson, 2005). However, foresters and hydrologists still debate the nature of the influence that forests have on water regulation (Kaimowitz, 2001; Innes *et al*., 2009). Climate change may make the role of forests in water regulation and soil protection more important, but the capacity of forests to fulfil this role may also be affected. Reductions in rainy-season flows and increases in dry-season flows are of little value when total annual rainfall is low and significant quantities of water are lost through evapotranspiration and are consumed by forests.

In areas, with frequent fogs, the clouds (horizontal rain), from which trees absorb moisture, may contribute significantly to total rainfall (Stadtmüller, 1994). A palaeoecological study of changes in Amazonian vegetation (Mayle and Power, 2008) indicated that, in cloud forests, where trees are often submerged in fog, warmer temperatures may cause the clouds to rise above the trees, reducing the potential for horizontal rain.

Water management and sustainable soil and land management are addressed in modules B6 and B7, respectively.

Socio-economic impacts

Climate change may increase forest growth in some areas and decrease it in others. The expected global increase in wood production could lead to lower prices, which would benefit consumers. However, lower prices and regionally differentiated impacts on productivity will have varying effects on incomes and employment derived from timber (Osman-Elasha *et al*., 2009). On all continents, except Australia, timber production may increase by up to 50 percent. Most of this increase, however, is expected to come from plantations with increasingly shorter rotations, and is therefore likely to be distributed unevenly among regions (Osman-Elasha *et al*., 2009). In South America, where the greatest increase is expected, current plantation production is concentrated in Argentina, southern Brazil, Chile and Uruguay. However, the possible dieback of natural tropical forests in South America may decrease timber production in the tropical zone.

The harvesting of non-wood forest products (NWFPs) has three major functions: 1) supplying part of the daily necessities of forest-dependent people; 2) generating off-farm income; and 3) providing a safety net in times of adverse conditions for agricultural production. Osman-Elasha *et al*. (2009) have suggested that climate change could have impacts on the productivity of NWFPs, and that greater numbers of people seeking emergency supplies or alternative sources of income would increase the importance of NWFPs. The value of NWFPs is likely to increase in areas where there is high poverty and an already high dependence on NWFPs, and where there is expected to be an increase in the frequency and intensity of extreme climate events (e.g. droughts, storms and floods) and other natural disturbances (e.g. pests, diseases and fire). The impacts of climate change on NWFPs and the subsequent socio-economic consequences require further study.

The impacts of climate change on forest-related cultural and recreational services are difficult to measure, and have not been extensively studied. Osman-Elasha *et al*. (2009) have reported on studies of well-defined recreational services in forested landscapes. One example comes from mountainous areas, where skiing activities at lower altitudes is likely to be affected by higher temperatures. The recreational value placed on forests is usually local, and most countries lack reliable projections of the impacts of climate change at the local scale. Osman-Elasha *et al*. (2009) have also indicated a need for further study of the impacts of climate change on forest biodiversity in Africa and its effects on tourism in national parks.

Vulnerabilities of forest-dependent poor

The expected increases in extreme weather events, such as heat waves, droughts and floods, and the increased risk of fire, pests and diseases will cause additional stress for large forest-dependent populations. The forest-dependent poor, who often rely directly on forests for their livelihoods and for meeting domestic needs related to energy, food and health, will be most vulnerable to these stresses. NWFPs can provide a safety net for rural and urban communities during food shortages. Agricultural crop failures may become more common due to climate change. This will increase the role forests play in providing a safety net and put more pressure on forest resources, especially during crises caused by extreme weather events. Unless properly addressed, the increasing difficulty faced by the forest-dependent poor in meeting basic needs for food, clean water and other necessities is likely to deepen poverty, lead to a deterioration in public health and increase social conflict. Given the risk that crop failures will increase due to climate change, diversifying livelihoods through forest-based products and services could increase the resilience of rural people, especially in areas where the potential of forests to provide livelihoods, for example, through NWFP production and ecotourism, is not yet fully realized.

Impacts on human health

In many parts of the world, climate change scenarios project that forest fires will be more frequent and that fire seasons will be longer. The intensity of the fires is also expected to be greater, which could have significantly harmful effects on human health. Changes in forest cover and biodiversity could reduce access to forest foods, medicines, other NWFPs and timber. This could also affect human health, directly, for example, by lowering the availability of medicinal plants, and indirectly, for example, through the loss of marketable goods. The impact on human health could be felt over the long term, if, for example, indigenous knowledge about medicinal plants is lost.

B3-1.3 The impact of forests on climate change - the need for mitigation

Changes to the global carbon cycle and their effect on concentrations of carbon dioxide in the atmosphere are crucial in shaping the global climate. Forests play important roles as both sinks and sources of carbon dioxide. Forest vegetation and soils (see module B7) contain about half the planet's terrestrial carbon, and terrestrial ecosystems have the potential to sequester more carbon dioxide than they currently do. Forests absorb carbon dioxide through photosynthesis, store it as carbon, and release it through respiration, decomposition and combustion. The capacity of a forest to act as a carbon sink increases with the forest's rate of growth and its ability to retain the carbon on a permanent basis. Vigorous young forests may sequester a great deal of carbon as they grow. In contrast, the vegetation and soils of old-growth forests typically store large quantities of carbon but add to these stocks at a slower rate.

Forests are also sources of greenhouse gas emissions, mainly carbon dioxide. These emissions, which are associated with deforestation and forest degradation, account for an estimated 17 percent of global greenhouse gas emissions. Climate change and increased climate variability have direct and indirect effects on forests and forest-dependent people. For example, there is a disturbing synergy between forest degradation caused by poor logging practices, forest fragmentation and increasingly severe droughts, which has made many Amazonian and Southeast Asian forests more prone to fire. In both boreal and tropical regions, climate change is increasing the susceptibility of forests to stresses that have long been present but which previously posed much lesser threats. When forests and associated social systems are unable to cope with the direct and indirect stresses associated with climate change, they may be considered to be vulnerable to it.

Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (known as REDD+) will be vital for global efforts to combat climate change. In the December 2015 Paris Agreement on climate change (UNFCCC, 2015), countries agreed to conserve and enhance carbon sinks and reservoirs, including forests. Accordingly, many nationally determined contributions, in which countries set out their responses to climate change, will require action related to agriculture, forests and other land uses.

To achieve the relevant Sustainable Development Goals and implement the actions needed to combat climate change, there is an increasing urgency to gain a better understanding of the drivers behind the conversion of forests to agriculture and vice versa.

Mitigation strategies in the forest sector can be grouped into four main categories: 1) reducing emissions from deforestation; 2) reducing emissions from forest degradation; 3) enhancing forest carbon sinks; and 4) product substitution. Product substitution involves the use of woodfuel instead of fossil fuels for energy and the use of wood fibre in place of materials, such as cement, steel and aluminium, whose production emits larger quantities of greenhouse gases.

Climate change mitigation measures, including those undertaken in forests, are needed urgently to help reduce anthropogenic interference in the climate system. However, these measures will only begin to have an effect on global mean surface temperature decades from now. Adaptation measures in forests (see chapter B3-1.2) will be required for many years to come to secure the continued delivery of forest goods and ecosystem services.

The forest sector can make a major contribution to the mitigation of global climate change, but realizing this potential requires coordinated actions across crop, livestock and forestry production systems. See module B1 and B2 on, respectively, crop and livestock mitigation actions. The special case of forestry in agriculture has been recognized in recent international efforts to support and coordinate national REDD+ efforts. This recognition reflects the significant greenhouse gas mitigation potential of forestry and agroforestry relative to other agriculture-related mitigation options. Forest degradation and deforestation are driven by two forces: the excessive harvesting of forest products (e.g. timber and woodfuel) and the comparative economic advantage of clearing forests for crop and livestock production (Cattaneo, 2008). The extensive literature on the indirect, or underlying, drivers of deforestation (e.g. Geist and Lambin, 2002; Hosonuma *et al.*, 2012; Pacheco *et al*., 2011) shows that developments in agriculture outside forest areas, whether they are related to pastures, crops or the production of biofuels from agricultural crops, can have a large impact on the drivers of deforestation (Cattaneo, 2005; Barona *et al*., 2010; Lapola *et al*., 2010; Cohn et al., 2014). To manage deforestation and forest degradation, the indirect effects of developments outside the formal forest sector must be taken into account and require landscape-level coordination of management strategies (see B3-3.1).

Many sustainable forest management practices have clear benefits for reducing forest degradation in forest landscapes (Boscolo *et al*., 2009). These within-landscape management approaches have important implications for the mitigation of climate change (see B3 Annex 4). However, their large-scale adoption may face multiple financial, institutional and policy-related barriers.

There is an important interaction between the potential for forests to store and sequester carbon and changes in temperature and precipitation. On the one hand, the more carbon that is stored in forests, the less there is in the atmosphere. Increasing stocks of forest carbon, therefore, will help reduce the rate of global warming. This relationship has become important in global discussions on climate change. Many tropical countries are preparing to reduce forest-related emissions and increase forest carbon stocks to capture part of the international funding that has been pledged for reducing greenhouse gas emissions. In Costa Rica, recognition of the carbon storage services of forests led, in the mid-1990s, to the implementation of innovative financing mechanisms for forest management, planted forests and forest conservation (Sánchez Chávez, 2009), and an increased effort to measure the extent of existing natural and planted forests and their carbon content. On the other hand, increasing temperatures, longer dry seasons and increasing carbon dioxide concentrations in the atmosphere are expected to reduce the capacity of forests to store and sequester carbon, possibly converting forests from carbon sinks to carbon sources (Nepstad *et al*., 2008; Ollinger *et al*., 2008; Saigusa *et al*., 2008; Clark *et al*., 2003). Because the rate of carbon sequestration partly depends on forest productivity, all factors that affect productivity will also affect carbon sequestration. In the short term, increasing temperatures may reduce carbon storage capacity. However, in temperate regions, the effect may vary by season. Early spring warming, for example, has been found to increase carbon sequestration in terrestrial ecosystems, and early autumn warming increases respiration more than the rate of sequestration (Keenan *et al*., 2014).

Elements of climate-smart forestry

Climate-smart forestry explicitly integrates the challenges and opportunities of climate change into forest policy, planning and practices. It is essential to mainstream national climate-smart forest strategies into existing policies and strategies on rural development, forests and climate change. Most national rural development and climate change policies already contain elements that support the development and implementation of climate-smart forestry. Efforts are needed, however, to ensure a coordinated vision that articulates priorities; identifies activities, institutions and policies to support such a vision; and defines the overall investment strategy.

Understanding the role of forestry in a national strategy for climate-smart agriculture requires a broad assessment of forest-related options and their potential impacts on food security and climate change adaptation and mitigation. These options may include reducing the expansion of agriculture into forest lands (see the strategies for sustainable crop production intensification in module B1); reducing forest degradation; improving the efficiency of charcoal and fuelwood use (see energy solutions for climate-smart agriculture in module B9); and agroforestry (discussed in module B5).

B3-2.1 Enhancing the contributions of forests and trees to food security and livelihoods

The most direct way in which forests and trees help ensure food security is through their contributions to diets and nutrition. Plants and animals found in forests provide households with important nutrient-rich foods. They often form a small but crucial part of otherwise bland and nutritionally poor diets, adding variety and improving the taste and palatability of staple foods.

Many tree species found on farms, as well as forest trees and the shrubs and grasses that grow under them, are used for animal feed, either as browse or collected and fed to livestock in stalls. It has been estimated that 75 percent of the tree species of tropical Africa are used as browse (FAO, 2011). Fodder trees contribute in several ways to the overall household food and nutritional security. For example, by significantly contributing to domestic livestock feed, they have a direct influence on milk and meat production. Tree fodder also helps maintain draught animals, which also produce manure that is used as organic fertilizer. Tree fodder and browse, which may consist of leaves, small branches, seeds, pods and fruits, can be used to supplement other sources of feed and can be key components of livestock diets in dry seasons, providing proteins, minerals and vitamins.

In most developing countries, woodfuel is the main source of energy for cooking and food processing (see module B9). The supply of woodfuel indirectly affects food stability, quality and quantity. In many rural areas, the dwindling supplies of woodfuel are having an increasingly severe impact on food security and nutrition. Research in rural Ghana, for example, has shown that the proportion of total household budgets spent on the purchase of woodfuel rose from 1 percent to over 15 percent over a five-year period (FAO, 2011). Woodfuel security is strongly linked to food security, and both are linked in multiple ways to climate change.

The wood and non-wood forest subsectors make substantial contributions to livelihoods. Globally, the value added in the wood-based forest subsector amounted to just over US$ 600 billion in 2011, which was 0.9 percent of the global economy. The NWFP subsector generated a further US$ 88 billion in income, and the informal production of woodfuel and forest products used for house construction generated US$ 33 billion. The subsector also made other smaller contributions to the economy. The total income generated by forests in 2011 was estimated to be about US$ 730 billion. The formal forest sector employs an estimated 13.2 million people worldwide, and at least another 41 million are employed in the informal sector (Rametsteiner and Whiteman, 2014).

B3-2.2 Reducing the vulnerability and increasing the resilience of forests and people

As in other land-use sectors, vulnerability to climate change in the forest sector has a number of dimensions, from local issues affecting individual households and communities to the more strategic considerations related to maintaining industry performance and national food supply.

Understanding and reducing vulnerability

A number of practical options exist for reducing the vulnerability of forest-dependent people to climate change (see, for example, B3 Annex 2 and B3 Annex 3). The choice of the most appropriate of these will depend on the location and scale of change; the emergence of impacts; the perception of effects; and the cost, complexity and time required to implement countermeasures. Priority may be given to the least-expensive changes in systems or practices that will bring about useful risk reduction. As the risks posed by climate change increase, however, such measures may quickly become redundant or, more dangerously, offer a false sense of security. On the other hand, early overinvestment in expensive forms of protection may also be dangerous or inequitable if they divert development resources away from some communities or stakeholder groups towards others. Trade-offs may be required to protect and strengthen the most vulnerable communities or resources at the expense of the less vulnerable.

Climate change threatens to increase the incidence and severity of a range of forest disturbances, such as pests (see B8-1), fires and storms, and this will demand increased management efforts. Forests should be taken into account in disaster risk management strategies to ensure adequate planning in the event of major forest disturbances and ensure that forests play their role in disaster mitigation (e.g. tree planting to prevent mudslides and minimize soil erosion) and management (e.g. as a source of food and materials in the aftermath of a disaster).

It is possible to strengthen the resilience of households, communities and national entities by targeting specific areas of vulnerability. If these areas are addressed only selectively or partially, however, remaining vulnerabilities may jeopardize or negate the anticipated benefits. Unresolved issues outside the forest sector could also act to limit the potential for strengthening resilience. The following key principles should be taken into account in any actions intended to build resilience:

- Systems with more diverse characteristics and components tend to have greater resilience.
- Efforts to build resilience can connect across different scales. Resilience in local communities can help increase resilience on a larger scale, and greater national resilience achieved, for example, through market and economic strategies can create a positive environment for strengthening local resilience.
- Trade-offs should be identified between the risks associated with vulnerability to climate change and the cost of building resilience.
- The risks posed by climate change may not be the only factors that increase the vulnerability of forests and forest-dependent people. All factors contributing to vulnerability should be considered.

B3-2.3 Addressing deforestation and forest degradation to help safeguard food security

Because forests provide ecosystem services essential for food production and a safety net during food shortages (e.g. in severe droughts and floods), reducing deforestation and forest degradation can help safeguard food security. Nkem *et al*. (2010) have proposed the inclusion of payment schemes for ecosystem services in livelihood adaptation plans. These schemes would focus on vulnerable segments of the population and take a pro-poor approach. Payment schemes for ecosystem services have a positive relationship with efforts to adapt to climate change. They increase the provision of ecosystem services; strengthen various elements of adaptive capacity; and provide an incentive mechanism for the providers of ecosystem services to adopt specific measures that support climate change adaptation (van de Sand, Mwangi and Namirembe, 2014). Climate change adaptation for food security in the forest sector will likely have positive impacts on other development goals, including poverty reduction, energy security, and greater community resilience to shocks.

Climate-smart forestry in practice

Forests are linked to climate change in four main ways. First, when they are cleared, overused, degraded and generally improperly managed, forests contribute up to one-sixth of global carbon emissions. Second, forests are vulnerable to changes in the climate. Third, when managed sustainably, forests produce woodfuels, which can be used as an alternative to fossil fuels to reduce greenhouse gas emissions. Fourth, forests have the potential to absorb about one-tenth of the carbon projected to be emitted globally in the first half of this century into their biomass, soils and products and, in principle, to store this carbon in perpetuity (FAO, 2012).

Climate-smart approaches in forestry are broadly similar to those in other sectors. As described in module A2, climate-smart initiatives are connected with most major crosscutting themes of development and environment. For this reason, it is expected that 'climate-smart' will become the default development approach. Key considerations for implementing a climate-smart approach to development in the forest sector include the need to:

- respond to considerable increases in global demand for wood and NWFPs in the face of climate change and other factors;
- address specific issues related to food access and the livelihoods of forest-dependent people across the supply, value and benefit chains;
- interact effectively with emerging technological, commercial and socially driven changes in, or associated with, the forest sector;
- identify gaps in capacity, efficiency and system resilience in the forest sector, particularly those gaps that are likely to increase under climate stress, and develop generic or specific actions to address them;
- identify options for strengthening the coordination of activities within the forest sector to improve, for example, the flow of goods and services, ensure efficient resource use and enhance functional resilience;
- connect activities in the forest sector in a coherent manner with other development objectives, including hunger eradication, poverty alleviation, natural resource protection and rehabilitation, nutritional safety and health, personal and community empowerment, self-determination and vulnerability reduction;
- ensure that responses are clearly recognizable and actionable by policy agents working effectively with practitioners and beneficiaries at all levels, and are based on clear evidence of functionality and effectiveness;
- sustainably manage forests to increase forest growth and carbon storage;
- use forest raw materials to manufacture products as a way of storing carbon;
- conserve forests to protect standing trees; provide ecosystem services, such as water replenishment and shelter for fauna; and sustain the livelihoods of forest-dependent indigenous peoples and local communities; and
- use forests and trees to reduce reliance on oil, coal and gas by delivering more raw materials for climate-smart products, such as biobased fuels and timber products.

Many lessons on climate-smart approaches can be learned from other agricultural sectors, but it is also clear that forestry has distinct characteristics, including the significant level of socio-economic dependence of many poor and marginalized people on forests and trees (FAO, 2014). This chapter presents various approaches to forest management. Policy approaches are addressed in chapter B3-4 .2.

Figure 2 illustrates the general pathway for integrating climate-smart practices into forestry. It applies to a given forest management unit (i.e. a well-defined and demarcated area, predominantly covered by forests, that is managed on a long-term basis and has a set of clear objectives specified in a forest management plan). This pathway generally involves the following 12 steps:

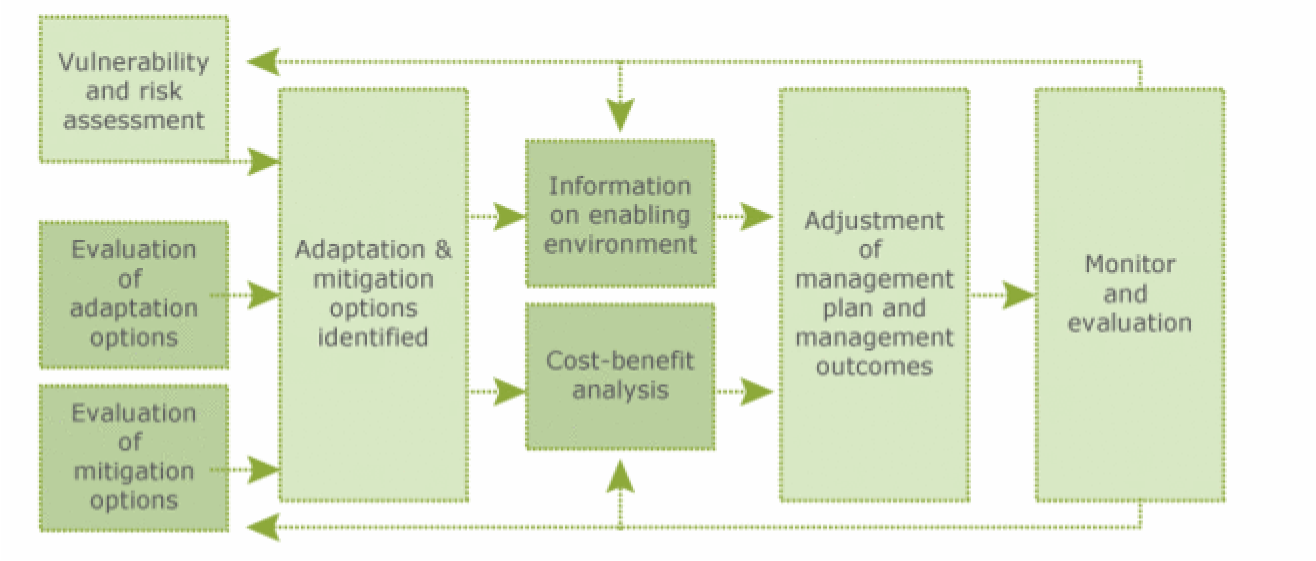
1. Assess the risk that climate change poses to the achievement of the management objectives of the forest management unit (i.e. the delivery of desired forest products and ecosystem services).
2. Identify the forest-dependent people and forest areas in (or close to) the forest management unit that are most vulnerable to the likely impacts of climate change.
3. Identify forest management measures that would reduce the vulnerability of forest-dependent people and forest areas to climate change, or would increase their adaptation capacity, and estimate the costs of implementing those measures in the forest management unit.
4. Gather information on policies, institutions and financial and technical incentives; the availability of support for undertaking adaptation measures; and the requirements for gaining access to such incentives and support.
5. Identify the options available in the forest management unit for mitigating climate change, including the actions to be taken, the schedule for taking such actions, the costs involved and the expected mitigation benefits.
6. Conduct a cost-benefit assessment to identify the most cost-effective mitigation and adaptation options, taking into consideration synergies and trade-offs between them.
7. Adjust the forest management plan and other planning tools to accommodate the identified mitigation and adaptation measures and incorporate the knowledge gained through assessments of vulnerability, risks and options for mitigation.
8. Identify capacity development needs and opportunities to implement mitigation and adaptation measures.
9. Adjust management practices to achieve the specified mitigation and adaptation goals.
10. Adjust forest monitoring and evaluation procedures to allow for additional responses that may be required in relation to the specified mitigation and adaptation actions.
11. Develop mechanisms to ensure the continual adaptation of forest management in response to the results of monitoring and evaluation.

Figure B3.2. Approach for adopting climate-smart practices in forestry

Vulnerability and risk assessment of climate change impacts and mitigation options

The scope and scale of assessments of vulnerability, risk and mitigation options carried out in the forest sector will depend on the following factors:

- the focal area of the assessments;
- the time available for the assessments;
- the questions to be addressed by the assessments and the decisions the assessments would support;
- the funds available for the assessments;
- the level of support from key stakeholders; and
- the value of the resources that may be at risk.



The goal of vulnerability and risk assessments is to identify the vulnerable groups in a given population, the ecological systems and that infrastructure that are vulnerable to climate change, and assess the risks of negative impacts. Climate change vulnerability assessments of forests and forest-dependent communities can involve a range of approaches and sources of information (e.g. local knowledge, expert opinion and detailed data collection and technical analyses). Box B3.4 outlines the steps to be taken when conducting forest-related vulnerability and risk assessments on climate change.

Box B3.4 Steps in conducting forest-related vulnerability and risk assessments on climate change

1. Identify the likely impacts of climate change on ecosystems and their ramifications for the well-being of forest-dependent communities.
2. Assess the vulnerability of forests and forest-dependent communities to these impacts. At the national level, government agencies and research institutions that collect and analyse climate-related information are likely to be involved in downscaling global and regional climate models to national and subnational levels. Vulnerability and risk assessments generally involve an analysis of climate sensitivity (Cardona *et al.*, 2012), followed by an evaluation of the capacity of ecosystems and communities to adapt to climate change. To analyse the sensitivity of forests and forest-dependent communities to changing climatic conditions, the following factors should be considered:

- the current and expected stresses on the forest area;
- the known climatic conditions, and how these affect the forest area;
- the projected changes in climatic conditions and the likely impacts of those changes on forests;
- the expected changes in stresses on a system as a result of the likely impacts of climate change;
- the capacity of the forest or forest-dependent community to adapt to climate change;
- the constraints on the capacity of the forest or forest-dependent community to accommodate changes in climatic conditions;
- estimates as to whether the projected rate of climate change is likely to be faster than the capacity of the forest or forest-dependent community to adapt; and
- ongoing efforts in the local area to address the impacts of climate change on forests and forest-dependent communities.

To determine the extent to which forests and forest-dependent communities are vulnerable to climate change, combine the findings of the climate sensitivity analysis and the evaluation of their capacity to adapt.

Assessment of adaptation options

After completing assessments to determine how forest ecosystems and forest-dependent communities will be affected by changing climatic conditions, the next step is to examine the management options that would reduce vulnerability, increase resilience and enable adaptation to climate change and climate variability.

Adaptation approaches can be grouped into two broad categories (FAO, 2013):

- **Adaptation of forests**, which refers to making forests more resilient to climate change. From a global perspective, several forest management interventions can be made, such as:
  - improving resilience through 'best practices' that address forest productivity, biodiversity, water availability and quality, fire, pests and diseases, extreme weather events, sea-level rise, and the economic, social and institutional context;
  - adapting management plans and practices to increase resilience, reduce risks and adapt to changes; and
  - *in situ* and *ex situ* genetic conservation (see chapter B8-5).
- Adaptation using forests, which involve measures to decrease the vulnerability of forest-dependent people to climate change. These measures may include:
  - the diversification of rural incomes and the provision of support for the establishment of small-and medium-sized forest enterprises;
  - the reinforcement of local and traditional coping strategies;
  - the maintenance of access to forests as 'safety nets';
  - adopting a 'rights-based approach' to adaptation measures, including land and resource tenure rights, the rights of indigenous peoples and community rights; and
  - the strengthening of local governance, including participatory and community-based governance.

These actions are intended to support forest managers and other stakeholders in dealing with the challenges of adapting to climate change. They are drawn mostly from existing forest management practices. However, these actions give greater consideration to the spatial and temporal aspects of climate change; the protection of forest communities; management measures to reduce vulnerability to expected changes and extreme climate-driven disturbances; and increased flexibility in forest management plans to deal with climate-related uncertainties and surprises.

Due to the fact that addressing the impacts of climate change while involve many jurisdictional issues and entail significant financial costs, responses cannot be undertaken by forest managers acting only at the local level. Effective responses to many of the impacts of climate change will need to be cross-sectoral and require action at a landscape, regional or national level. To prepare for these impacts, coordination is needed among government agencies, non-governmental organizations and stakeholders in multiple sectors (e.g. natural resources, public health and safety, emergency and disaster risk management, recreation, and economic development).

Assessment of mitigation options

The benefits of climate change mitigation initiatives in forests must be weighed against their costs, and the impacts, both negative and positive, they will have on meeting other forest management objectives. The aim should be to maximize the economic and social benefits and minimize the social and environmental costs of adjusting forest management plans to mitigate climate change.

Mitigation options can be grouped into four general categories:

1. maintaining the area under forest by reducing deforestation and promoting forest conservation and protection;
2. increasing the area under forest (e.g. through afforestation and reforestation);
3. maintaining or increasing carbon density of forest stands and landscapes with forests, by avoiding forest degradation and managing timber production so that, on average, carbon stocks remain constant or increase over time, and restoring degraded forests; and
4. increasing off-site carbon stocks in harvested wood products.

To assess the suitability of these options in a given forest area, information is required on:

- national policies and regulations related to incentives to undertake mitigation actions and any potential disincentives;
- the feasibility of mitigation options, given existing forest cover and current forest management objectives;
- the potential for maintaining or increasing forest carbon stocks, and thereby reducing greenhouse gas emissions over time as a result of adjusting management plans or practices;
- requirements for measuring forest carbon and verifying mitigation;
- requirements for ensuring there is no 'leakage', which can result, for example, when changes in the management of a forest management unit lead to increases in greenhouse gas emissions elsewhere;
- the capacity to provide evidence that mitigation measures were 'additional' to business-as-usual forest management practices;
- the actual costs, the opportunity costs and the benefits of implementing and monitoring the mitigation actions; and
- the likely positive and negative economic, social and environmental side-effects of implementing the mitigation actions.

After completing assessments to determine how forest ecosystems and forest-dependent communities will be affected by changing climatic conditions, the next step is to examine the management options that would reduce vulnerability, increase resilience, and enable adaptation to climate change and climate variability. Although these options may be drawn from existing forest management practices, their implementation must give greater consideration to spatial and temporal aspects of climate change; the protection of forest communities; the management measures to reduce vulnerability to expected changes and extreme climate-driven disturbances; and assurances that there is enough flexibility in forest management plans to deal with climate-related uncertainties and surprises.

Forest monitoring

Forest monitoring, which detects changes in forests due to climate change, natural disturbances and human activities, has become an essential element in REDD+ and other efforts to mitigate climate change in the forest sector. Given the benefits that accurate carbon monitoring could bring within the REDD+ framework, forest-monitoring practice has developed considerably in recent years, and its accuracy has increased accordingly, along with acceptance of its necessity.

Successful monitoring has clear objectives, is as simple as possible, and provides benefits for those people who invest time and/or money in it. Often, the objectives of monitoring may be clear, but the activities needed to achieve them are vague. This may be in part due to a lack of certainty on how the climate will change and consequently which elements of forests and forest management should be monitored. FAO and partners have developed several tools and methodologies, such as Collect Earth (see Box B3.5), to support countries in monitoring, measuring, reporting and verification (see module C10).

Box B3.5 Collect Earth

Collect Earth is a tool that enables data collection from remote sensing images. In conjunction with Google Earth, Bing Maps and Google Earth Engine, users can analyse high- and very-high-resolution satellite imagery for a wide variety of purposes, such as:

- supporting multiphase national forest inventories;
- conducting assessments of land use, land-use change and forestry;
- monitoring agricultural land and urban areas;
- validating existing maps;
- collecting spatially explicit socio-economic data; and
- quantifying deforestation, reforestation and desertification.

Collect Earth's user-friendliness and smooth learning curve make it an efficient tool for performing fast, accurate, cost-effective assessments. It is highly customizable for specific data collection needs and methodologies. Data gathered through Collect Earth are exportable to commonly used formats and can also be exported to Saiku, a tool that facilitates data analysis.

For more information, go to Collect Earth

Monitoring helps identify changes and evaluate trends, but it does not necessarily indicate the reasons behind the changes and trends. An important step, therefore, is to analyse the collected data to determine the whether there is a need to adapt the forest management approach.

Discussions on the implementation of REDD+ are taking place at the national level, but most monitoring experience has been obtained from forest management units. Although the monitoring needs at these two levels differ, they are highly complementary, and consideration should be given to linking them in the carbon monitoring system. It is essential that all stakeholders are involved in decisions on monitoring methodologies and variables. The involvement of local actors has been shown to have two advantages: it is less expensive than alternatives methods; and it creates greater ownership of monitoring results (Skutsch *et al*., 2009). Under the United Nations Framework Convention on Climate Change, national forest monitoring systems should be built on three 'pillars' to support the development of REDD+ (Box B3.6).

Box B3.6 National forest monitoring systems

The three-pillar national forest monitoring system approach to monitoring forest-based emissions is based on the following methodological equation proposed by the Intergovernmental Panel on Climate Change:

emissions (E) = activity data (AD) x emission factors (EF).

Each element of this equation represents a pillar of the forest monitoring system. The monitoring function will be nationally specific and can encompass the needs of REDD+ and other mechanisms. However the focus should be on two aspects of monitoring that are specific to REDD+:

1. monitoring to assess the performance of REDD+ demonstration activities in Phase 2 of REDD+ implementation; and
2. monitoring the performance of national REDD+ policies and measures in Phase 3 of REDD+ implementation.

The performance of REDD+ activities, policies and measures can be assessed through the direct monitoring of carbon stocks and removals, and indirectly through proxy indicators (e.g. forest canopy changes and forest certification schemes). The three essential elements of national forest monitoring systems are:

1. a satellite land-monitoring system to collect and assess activity data (i.e. AD in the equation above) related to forestlands;
2. a national forest inventory to collect information on forest carbon stocks and changes for estimating emissions and removals and provide emissions factors (i.e. EF); and
3. a national greenhouse gas inventory as a tool for reporting on anthropogenic forest-related emissions (i.e. E) by sources and removals by sinks to the Secretariat of the United Nations Framework Convention on Climate Change.

More information: National Forest Monitoring Systems: Monitoring and Measurement, Reporting and Verification (M & MRV) in the context of REDD+ Activities

Monitoring climate-induced changes in forests

Ensuring that forests can adapt to climate change requires an understanding of the changes in forests that may occur due to climate change and the extent to which adaptation may be necessary and desirable. General scenarios of forest change can be developed based on projections of global and regional climate change (Fischlin *et al*., 2009; Jimenez *et al*., 2009), but the precise nature of these changes is not well known. The reasons for this relate to the scale at which climate change projections are made; uncertainties in climate change models; and a lack of knowledge on the adaptive capacity of species and the ecological communities of which they are part, and how the effects of the interactions between species will affect adaptive capacity. In some forests, drastic changes have been projected. The northeastern Amazon, for example, could lose most of its forest cover because of massive forest dieback due to drought, giving rise to savannah vegetation (Malhi *et al*., 2008). However, the rate of change and exact outcomes are unclear (Mayle and Power, 2008).

To provide forest managers with sufficient information on which to base decisions, adaptation strategies should include monitoring systems on climate, vegetation, fauna and essential non-biological components of forests, such as water availability. Monitoring systems are especially important in forestry because of the long time lag between management actions and forest responses. The monitoring of permanent sample plots has always been integral to sustainable forest management.

To analyse the effects of climate change on forests, a combination of remote sensing for detecting change in forest area and a network of permanent sample plots for detecting change in forest quality may be the most appropriate strategy. Given its specialized nature, monitoring through remote sensing may best be carried out at the landscape, subnational or national level. It will require that all potential users of the monitoring information agree on a common set of variables based on their usefulness in supporting forest management decisions under changing climate conditions (Peterson *et al*., 1999).

Strengthening the capacity of forests to respond to climate change

The adaptive capacity of forests can be understood as their inherent ability to adjust to changing conditions by moderating the harm caused by these changes and taking advantage of the opportunities these changes open up (Locatelli *et al*., 2010). Strengthening adaptive capacity involves increasing the resistance or resilience of a forest to change. It also may involve adapting the forest to new conditions by facilitating changes in the ecosystem, for example through the introduction of certain species. In general, the purpose of strengthening the adaptive capacity of forests is to maintain, restore or enhance forest area, biodiversity and forest health and vitality. Many of the actions aimed at mitigating climate change through REDD+ have strong potential synergies with actions designed to strengthen forest adaptive capacity, especially if such actions consider ecological safeguards, such as biodiversity conservation.

Most of the experience in strengthening forest adaptive capacity in the face of climate change has been gained in tree plantations and agroforestry systems. These systems tend to have simpler structures and composition than natural forests. This makes it easier to detect changes due to climate change and design and implement mechanisms to strengthen adaptation. Designing such mechanisms is much more difficult in complex natural forests, especially in the tropics. However, plantations and agroforestry systems, precisely because of their simplicity, may also be more vulnerable to climate change, and their need for adaptation measures may be greater. In these systems, adaptation measures are often designed to increase diversity (e.g. see recommendations by Innes *et al*., 2009).

Creating an enabling environment and removing barriers for adoption of climate-smart forestry

B3-4.1 Synergies and trade-offs

Because of inertia in the climatic and socio-economic systems that determine the extent of anthropogenic greenhouse gas emissions, a certain amount of climate change is inevitable. Climate change is going to have an impact regardless of mitigation strategies. Nevertheless, the sooner mitigation activities begin, the less pronounced the likely impacts will be. Adaptation measures are needed to protect livelihoods and food security, especially in the developing countries that are expected to be most vulnerable to climate change.

A major challenge for climate policy is to find the most efficient mix of mitigation and adaptation measures for limiting the impacts of climate change. Many mutually reinforcing measures exist to achieve both mitigation and adaptation. If these measures are put in place, they can help ensure the efficient allocation of resources designated for climate responses and at the same time foster sustainable development (Ravindranath, 2007). Many of the potential synergies between efforts to mitigate the impacts of climate change and efforts to adapt to these impacts are found in the relationships that exist between the forest sector and the agriculture sectors. These synergies are particularly important to rural livelihoods in developing countries.

Mitigation efforts will be most effective and sustainable if they integrate adaptation measures for both communities and ecosystems. This would bring about 'climate-proof' mitigation. Forests need to adapt to climate change to maintain ecosystem functionality. A functioning forest ecosystem provides ecosystem services that reduce the vulnerability of local communities to climate change. By reducing pressure to clear forests and conserving biodiversity hotspots, mitigation actions have huge potential for facilitating forest adaptation. Mitigation actions can also help build the adaptive capacities of local people by increasing the supply of ecosystem services on which they rely. This can help diversify incomes, develop economic activities and infrastructure, increase social services and strengthen local institutions.

Forest adaptation measures can ensure the continuation or an increase of ecosystem services and augment carbon stocks, which contribute to climate change mitigation. For example, the restoration of mangroves in coastal areas will build the adaptive capacities of local communities by protecting coastal areas and diversifying incomes and livelihoods. Restoring mangroves will also contribute to mitigation by increasing the amount of carbon stored in the agricultural ecosystem. Other measures, such as sustainable forest management, agroforestry and community-based forestry, can support mitigation by increasing carbon stocks in biomass and soil. Adaptation alone is insufficient to deal with the impacts of climate change. Mitigation is required to reduce the magnitude of its impacts. A well-developed and sustainable adaptation plan that includes mitigation measures can benefit from climate and carbon funding and capacity building through international instruments such as REDD+.

One of the many dilemmas that countries face when confronting climate change is how to meet the political and moral imperative of responding to urgent immediate needs while also investing sufficient resources to meet future needs as the effects of climate change become more severe. Although governments will certainly face trade-offs, they should not lose sight of the opportunities that exist to capture synergies among the various approaches that can help meet both short-term and long-term objectives.

Improving forest management can tap into many of these synergies. In the short term, forests can help buffer communities and societies from climatic events, such as droughts, storms, floods and landslides. For example, forests can provide coastal areas with physical protection from storms, and forest-based ecosystem services can help regulate hydrological flows when rainfall patterns change. Forest-based foods and other products that can be consumed or sold for income and provide a safety net when agricultural livelihoods are affected by drought. The ability of forests to supply goods and ecosystem services is compromised when they are degraded or converted to other uses. Degradation also reduces the resilience of forests to climate change. For example, forests subject to fragmentation or unsustainable logging practices are more vulnerable to fire than intact forests. Investing in sustainable forest management would be a synergistic climate response that prepares communities both for droughts in the immediate future and for a projected long-term shift in rainfall patterns.

Forest-based approaches to climate change adaptation, such as those described in chapter B3-2.2. can complement or be a substitute for the construction of hard infrastructure. They also provide more flexibility in the implementation of adaptation strategies. In light of the many benefits currently provided by forests, this way of proceeding can be categorized as a 'no regrets' approach to climate change adaptation. In particular, investment in sustainable forest management as an adaptation strategy yields a 'double dividend' that also delivers mitigation benefits.

Protecting and sustainably managing forests requires responses at the all levels, from the community level to the global level. In implementing these responses, there is a risk of creating 'winners' and 'losers'. Local people may be required to implement measures that provide them with little or no benefit even though these measures, by averting emissions from deforestation and forest degradation, contribute to reducing the global risk of catastrophic climate change.

In an effort to distribute more equitably the costs and benefits of forest-based mitigation measures, finance is being mobilized through REDD+. This financing has the potential to support forest protection and sustainable management and compensate communities for any losses of income they might incur. Depending on how the benefits of REDD+ are shared at the national and local levels, forest protection and sustainable management could help finance rural development or make certain stakeholders worse off. There is an important trade-off between the short-term risk that REDD+ initiatives might disadvantage vulnerable forest-based communities and the potentially large mitigation benefits that REDD+ might yield to the global community.

Globally, REDD+ funds are likely to be targeted at forests that have high conservation value and large stocks of carbon. Other sources of finance will be needed to address adaptation challenges in the areas most affected by climate variability, such as the dry forests of sub-Saharan Africa. To minimize zero-sum trade-offs, governments should build adaptation synergies into the design of forest interventions funded by REDD+ and reserve scarce adaptation funds for targeting action in forests with low stocks of carbon.

The poor governance and weak institutions that characterize forest management in many countries present a challenge. To fully realize the adaptation and mitigation benefits of sustainable forest management, governments will need to confront those vested interests who seek to maintain the status quo. They will also need to make significant investments in institutional infrastructure, which is often lacking at the national and local levels. This infrastructure is needed to link forest communities with higher levels of government, facilitate intersectoral collaboration and provide citizens with a meaningful voice in the design of mitigation and adaptation strategies. These investments involve few short-term and long-term trade-offs because many of the same governance and institutional capacities needed to meet immediate development needs and reduce disaster risks are the same as those needed to prepare for climate change.

Making trade-offs between current needs and future welfare, allocating costs and benefits across stakeholder groups, and managing risks all require inherently political decisions. In this regard, governments should invest energy and resources in the following crucial 'no regrets' activities:

- informing their citizens of the mitigation and adaptation choices to be made;
- putting in place democratic processes to enable the meaningful participation of citizens in making those choices; and
- promoting engagement in efforts to mitigate and adapt to climate change.

B3-4.2 Policy approaches

National forest programmes (NFPs) are comprehensive forest policy frameworks for implementing sustainable forest management at the national level. They comprise the following three elements:

1. forest policies and forest-related policies;
2. forest-related legislation; and
3. institutional frameworks, including organizational structures and mechanisms for coordination and participation.

NFPs were established to enable countries to integrate various forest-related policy processes and initiatives under one umbrella and approach, and to strengthen cross-sectoral consistency among various forest-related policies. NFPs can provide an effective framework for efforts to mitigate and adapt to climate change in areas that are related to forests and linked to other land uses. By integrating climate change mitigation and adaptation goals with NFPs, climate change objectives can be balanced with other forest management objectives, and synergies can be created with other forest-related processes, such as forest law enforcement, governance and trade initiatives.

To ensure they are up to date and reflect emerging issues and opportunities, NFPs need to be dynamic and iterative, with interconnected phases of data collection and analysis, planning, implementation, and monitoring and evaluation. The principles underpinning NFPs are summarized below.

1. **National sovereignty and country leadership**. A nation has the right to manage its forest resources in accordance with its perceived needs and interests.
2. **Consistency within and beyond the forest sector**. NFPs must consider the economic, social and environmental dimensions of forests, and be consistent with national economic development planning, poverty reduction strategies, macroeconomic policy frameworks and other relevant strategies.
3. **Partnership and participation**. It is import to involve all forest stakeholders in decision-making and policy implementation. This includes all people who depend on, or benefit from, the use of forest resources and those who decide on, control or regulate access to these resources. Partnerships and participation can operate at a range of levels, from the national level to the local level.

These principles and the NFP approach support the efforts of countries to institute good forest governance through accountability, effectiveness, efficiency, fairness, equity, participation and transparency.

Integrating climate change into NFPs requires adapting forest-relevant policies and revising related laws; adapting existing organizations; adjusting coordination and participation mechanisms; and ensuring coherence, consistency and coordination with national climate change policies and strategies.

Conclusions

Deforestation causes nearly 20 percent of global emissions - more than the world's transport sector. Forests play important roles in the concentration of greenhouse gases in the atmosphere, absorbing 2.6 billion tonnes of carbon dioxide each year, about one-third of the carbon dioxide released by the burning of fossil fuels (CIFOR, undated) . The capacity of forests to remove carbon from the atmosphere decreases as they are cut down. Forest loss and forest degradation are both causes and effects of climate change. Reducing forest loss will reduce carbon emissions.

Forests are crucial for reducing emissions from the agriculture and land-use sectors. They are also important for reducing the effects of climate change on people, and maintaining and strengthening food security. As the REDD+ debate has made clear, the mitigation role of forests and trees has become prominent in climate change policy. Forest communities should leverage their potential role in greenhouse gas emission reductions in ways that ensure that their food security and adaptation needs are not compromised. A climate-smart agriculture strategy that ignores the role of forests and trees will undermine policies to reduce deforestation.

Actions for climate-smart forestry are needed both across and within landscapes. Even on land located far from forests, increases in agricultural productivity would reduce pressures to clear forests and at the same time increase food availability. A diverse set of within-landscape management practices exists that can improve food security, mitigate greenhouse gas emissions, or both. However, the adoption of such practices is often limited by a lack of information and by financial and institutional frameworks that constrain climate-smart agriculture policies and investment strategies. Most countries already have agricultural development plans, forest policies and national climate change policies and strategies. Efforts should be undertaken to formulate a coordinated vision that integrates these initiatives into a coherent investment strategy. The development of a national climate-smart agriculture strategy presents an opportunity to promote coordination among stakeholders working in agricultural development, forestry and climate change. It can bring them together to articulate a unified vision of agricultural development in the face of climate change.

Acknowledgements

Coordinating lead author: Simmone Rose (FAO)

Reviewers: Kristin Devalue (FAO), Nina Lande (FAO), Doug Muchoney (FAO), Maria Ruiz-Villar (FAO).

Notes: New module

References

Aragão, L. E. O. C., Malhi, Y., Barbier, N., Lima, A., Shimabukuro, Y., Anderson, L. & Saatchi, S. 2008. Interactions between rainfall, deforestation and fires during recent years in the Brazilian Amazonia. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1498): 1779-1785.

Arneth, A., Harrison, S. P., Zaehle, S., Tsigaridis, K., Menon, S., Bartlein, P. J., Feichter, J., Korhola, A., Kulmala, M., O'Donnell, D., Schurgers, G., Sorvari, S. & Vesala, T. 2010. Terrestrial biogeochemical feedbacks in the climate system. *Nature Geoscience* 3, 525 - 532

Barona, E., Ramankutty, N., Hyman, G. & Coomes, O.T. 2010. The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters*, 5 (2): 9.

Bauer, Z., Trnka, M., Bauerova, J., Mozny, M., Stepanek, P., Bartosova, L. & Zalud, Z. 2010. Changing climate and the phenological response of great tit and collared flycatcher populations in floodplain forest ecosystems in Central Europe. *International Journal of Biometeorology* 54 (1): 99-111.

Berkes, F. 2008. Sacred ecology. Second edition. Routledge, New York.

Blanke, M. & Kunz, A. 2009. Einfluss rezenter Klimaveränderungen auf die Phänologie bei Kernobst am Standort Klein-Altendorf - anhand 50-jähriger Aufzeichnungen. *Erwerbs-Obstbau* 51(3): 101-114.

Boscolo, M., Snook, L.K. & Quevedo, L. 2009. Adoption of sustainable forest management practices in Bolivian timber concessions: a quantitative assessment. *International Forestry Review*, 11(4): 514-523.

Breshears, D. D., Huxman, T. E., Adams, H.D., Zou, C.B. & Davison, J.E. 2008. Vegetation synchronously leans upslope as climate warms. *Proceedings of the National Academy of Sciences* 105(33): 11591-11592.

Burton, P.J., Bergeron, Y., Bogdansky, B.E.C., Juday, G.P., Kuuluvainen, T., McAfee, B.J., Ogden, A., Teplyakov, V.K., Alfaro, R.I., Francis, D.A., Gauthier, S. & Hantula, J. 2010. Sustainability of boreal forests and forestry in a changing environment. In: Mery, G., Katila, P., Galloway, G., Alfaro, R., Kanninen, M., Lobovikov, M., Varjo, J., (eds) 2010. *Forests and society - responding to global drivers of change*. IUFRO World Series Vol. 25. Pp 249-282.

Cattaneo, A. 2005. Inter-regional innovation in Brazilian agriculture and deforestation in the Amazon: income and environment in the balance. *Environment and Development Economics*, 10(04): 485-511.

Cattaneo, A. 2008. Regional comparative advantage, location of agriculture, and deforestation in Brazil. *Journal of Sustainable Forestry*, 27(1-2): 25-42. Chakraborty et al., 2008.

CIFOR. Undated. Forests and climate change. Webpage (available at www.cifor.org/forests-and-climate-change).

Accessed June 2017. *Center for International Forestry Research* (CIFOR).

Clark, D.A., Piper, S.C., Keeling, C.D. & Clark, D.B. 2003. Tropical rain forest tree growth and atmospheric carbon dynamics linked to interannual temperature variation during 1984-2000. *PNAS* 100 (10): 5852-5857.

Cohn, A.S., Mosnier, A., Havlík, P., Valin, H., Herrero, M., Schmid, E., O'Hare, M. & Obersteiner, M. 2014. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proceedings of the National Academy of Sciences*, 111(20): 7236-7241.

Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

FAO. 2007. *Fire management : global assessment 2006 : a thematic study prepared in the framework of the Global forest resources assessment 2005*. Rome.

FAO. 2009. *Situación de los bosques del mundo 2009.* Rome.

FAO. 2010. *Global forest resources assessment 2010:full report*. FAO Forestry Paper 163. Rome.

FAO. 2011. *Forests for improved nutrition and food security*. Rome.

FAO. 2012. *Roles of forests in climate change*. Webpage. Accessed June 2017.

FAO. 2013. *Climate change guidelines for forest managers*. FAO Forestry Paper No. 172. Rome.

FAO. 2014. *State of the World's Forests: Enhancing the socioeconomic benefits from forests.* Rome.

Feeley, K.J., Wright, S.J., Nur Supardi, M.N., Kassim, A.R. & Davies, S.J. 2007. Decelerating growth in tropical forest trees. *Ecology Letters* 10: 461-469.

Fischlin, A., Ayres, M., Karnosky, D., Kellomäki, S., Louman, B., Ong, C., Plattner, C., Santoso, H., Thompson, I, Booth, T., Marcar, N., Scholes, B., Swanston, C. & Zamolodchikov, D. 2009. Future environmental impacts and vulnerabilities. In: Seppala, R., Buck, A. & Katila, P. 2009. *Adaptation of forests and people to climate change. IUFRO World Series 22*. Geist and Lambin, 2002.

Geist, H. J., Lambin, E. F. 2002. P*roximate causes and underlying driving forces of tropical deforestation: tropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations*. Bioscience, 52: 143-150.

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., Peres, C. A., Bradshaw, C. J. A., Laurance, W. F., Lovejoy, T. E. & Sodhi, N. S. 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* 478, 378-381.

Girardin, M. P., Raulier, F., Bernier, P.Y. & Tardif, J.C. 2008. Response of tree growth to a changing climate in boreal central Canada: A comparison of empirical, process-based, and hybrid modelling approaches. *Ecological Modelling* 213(2): 209-228.

Gordo, O. & Sanz, J.J. 2010. Impact of climate change on plant phenology in Mediterranean ecosystems. *Global Change Biology* 16 (3): 1082-1106.

Held, I. M., T. L. Delworth, J. Lu, K. L. Findell, and T. R. Knutson., 2005. Simulation of Sahel drought in the 20th and 21st centuries. Proc. Nat. Acad. *Science*, 102, 17891-17896.

Helms, J. A., 1998. *The Dictionary of Forestry.* Society of American Foresters.

Hosonuma, N.M., Herold, V., De Sy, R.S., De Fries, M., Brockhaus, L., Verchot, A., Angelsen, E. & Romijn, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, 7: 044009.

Innes, J., Joyce, L.A., Kellomäki, S., Louman, B., Ogden, A., Parrotta, J., Thompson, I., Ayres, M., Ong, C., Santoso, H., Sohngen, B. & Wreford, A. 2009. Management for adapatation. In: Seppala, R., Buck, A. & Katila, P. 2009. *Adaptation of forests and people to climate change*. IUFRO World Series 22.

Jepsen, J. U., Hagen, S. B., Ims, R.A. & Yoccoz, N.G. 2008. Climate change and outbreaks of the geometrids Operophtera brumata and Epirrita autumnata in subarctic birch forest: evidence of a recent outbreak range expansion. *Journal of Animal Ecology* 77 (2): 257-264

Ræbild, A., Larsen, A. S., Jensen, J. S., Ouedraogo, M., De Groote, S., Van Damme, P., Bayala, J., Diallo, B.O., Sanou, H., Kallinganire, A. & Kjær, E. D. 2011. Advances in domestication of indigenous fruit trees in the West African Sahel. *New Forests*, 41(3), 297-315

Jimenez, M., Finegan, B., Herrera, B., Imbach, P. & Delgado, D. 2009. R*esiliencia de las zonas de vida de Costa Rica al cambio climático*. Presentación XIII World Forestry Congress, Argentina, 18-23 October 2009.

Kaimowitz, D. 2001. *Cuatro medio verdades: la relación bosques y agua en Centroamérica*. Revista Forestal Centroamericana (33): 6-10.

Keenan T.F., Gray, J., Friedl, M., Toomey, M., Bohrer, G., Hollinger, D.Y., Munger, J.W., O'Keefe, J., Schmid, H.P., Sue Wing, I., Yang, B., Richardson, A.D. 2014. Net carbon uptake has increased through warming-induced changes in temperate forest phenology. *Nature Climate Change*, 4, 598-604.

Kurz, W. A., Stinson, G., Rampley, G.J., Dymond, C.C. & Neilson, E.T. 2008. Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. *Proceedings of the National Academy of Sciences* 105 (5): 1551-1555

Lapola, D., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Kölking, C. & Priess, J. 2010. Indirect land-use changes can overcome carbon savings by biofuels in Brazil. *Proceedings of the National Academy of Sciences of the USA*, 107: 3388-3393.

LeBauer, D. S. & Treseder, K. K. 2008. Nitrogen limitation of net primary productivity in terrestrial ecosystems is globally distributed. *Ecology* 89 (2): 371-379

Locatelli, B., Brockhaus, M., Buck, A., Thompson, I., Bahamondez, C., Murdock, T., Roberts, G. & Webbe, J. 2010. Forests and adaptation to climate change: challenges and opportunities. In: Mery, G., Katila, P., Galloway, G., Alfaro, R., Kanninen, M., Lobovikov, M., Varjo, J. eds. 2010. *Forests and society - responding to global drivers of change*. IUFRO World Series Vol. 25.

Lucier, A., Ayres, M., Karnosky, D., Thompson, I., Loehle, C., Percy, K. & Sohngen, B. 2009. Forest responses and vulnerabilities to recent climate change. In: Seppala, R., Buck, A. & Katila, P. 2009. *Adaptation of forests and people to climate change*. IUFRO World Series 22.

Malhi, Y., Timmons Roberts, J., Betts, R.A., Killeen, T.J., Li, W. & Nobre, C.A. 2008. Climate change, deforestation, and the fate of the Amazon. *Science* 319(5860): 169-172.

Mayle, F. E. & Power, M. J. 2008. Impact of a drier early-mid Holocene climate upon Amazonian forests. *Philosophical Transactions of the Royal Society B, Biological Sciences* 363(1498): 1829-1838.

McMillan, A. M. S., Winston, G. C. & Goulden, M.L. 2008. Age-dependent response of boreal forest to temperature and rainfall variability. *Global Change Biology* 14 (8): 1904-1916.

Nepstad, D. C., Stickler, C. M., Soares-Filho, B. & Merry, F. 2008. Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. *Philosophical Transactions of the Royal Society B, Biological Sciences* 363 (1498): 1737-1746.

Nkem, J., Kalame, F.B., Idinoba, M., Somorin, O.A., Ndoye, O., Awono, A., 2010. Shaping forest safety nets with markets: adaptation to climate change under changing roles of tropical forests in Congo Basin. *Environmental Science and Policy* 13, 498-508.

Ollinger, S., C. Goodale, Hayhoe, K. & Jenkins, J.P. 2008. Potential effects of climate change and rising CO2 on ecosystem processes in northeastern U.S. forests. *Mitigation and Adaptation Strategies for Global Change* 13 (5): 467-485.Osman-Elasha et al., 2009.

Osman-Elasha, B., Parrotta, J., Adger, N., Brockhaus, M., Pierce Colfer, C.J., Sohngen, B., Dafalla, T., Joyce, L.A., Nkem, J. & Robledo, C. 2009. Future socioeconomic impacts and vulnerabilities. In: Seppala, R., Buck, A. & Katila, P. *Adaptation of forests and people to climate change*. IUFRO World Series 22.

Pacheco P., Aguilar-Støen, M., Börner, J., Etter, A., Putzel, L. & Vera Diaz, M.C. 2011. Landscape transformation in tropical Latin America: assessing trends and policy implications for REDD+. *Forests,* 2: 1-29

Parrotta, J., Youn Y.-C. & Camacho, L.D. 2016. Traditional knowledge for sustainable forest management and provision of ecosystem services. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 12(1-2): 1-4.

Peterson, D.J., Resetar, S., Brower, J. & Diver, R. 1999. *Forest monitoring and remote sensing. A survey of accomplishments and opportunities for the future*. RAND Science and technology Policy Institute, Washington DC

Phillips, O.L., Lewis, S.L., Baker, T.R., Chao, K-J. & Higuchi, N. 2008. The changing Amazon forest. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363 (1498): 1819-1827.

Pielke, R. A., Pitman, A., Niyogi, D., Mahmood, R., McAlpine, C., Hossain, F., Goldewijk, K. K., Nair ,U., Betts, R., Fall, S., Reichstein, M., Kabat, P. & de Noblet-Ducoudré, N. 2011. Land use/land cover changes and climate: modeling analysis and observational evidence. *WIREs Climate Change,* Vol 2; Issue 6; pp. 828-850

Postel, S.L. & Thompson, B.H. 2005. Watershed protection: capturing the benefits of nature's water supply services. *Natural Resources Forum* 29(2):98-108.

Rametsteiner, E. & Whiteman, A. 2014. The socioeconomic benefits of forests. *Tropical Forest Update,* 23(2): 3-6.

Ravindranath, N.H. 2007. Mitigation and adaptation synergy in forest sector. *Global Change* 12: 843.

Reich, P. B. & Oleksyn, J. 2008. Climate warming will reduce growth and survival of Scots pine except in the far north. *Ecology Letters* 11 (6): 588-597

Rosenzweig, C., Casassa, G., Karoly, D.J., Imeson, A., Liu, C., Menzel, A., Rawlins, S., Root, T.L., Seguin, B. & Tryjanowski, P. 2007. Assessment of observed changes and responses in natural and managed systems. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment*

Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, Cambridge, UK.

Saigusa, N., Yamamoto, S., Hirata, R., Ohtani, Y., Ide, R., Asanuma, J., Gamo, M., Hirano, T., Kondo, H., Kosugi, Y., Li, S-G., Nakai, Y., Takagi, K., Tani, M. & Wang, H. 2008. Temporal and spatial variations in the seasonal patterns of CO2 flux in boreal, temperate, and tropical forests in East Asia. *Agricultural and Forest Meteorology* 148 (5): 700-713.

Sánchez Chávez, O. 2009. El pago por servicios ambientales del Fondo Nacional de Financiamiento Forestal (FONAFIFO), un mecanismo para lograr la adaptación al cambio climático en Costa Rica. In: Sepúlveda, C. & Ibrahim, M. eds. *Políticas y sistemas de incentivos para el fomento y adopción de buenas prácticas agrícolas, como una medida de adaptación al cambio climático en América Central*. Serie técnica No. 37, CATIE, Turrialba, Costa Rica.

Shanahan, T.M., Overpeck, J.T., Anchukaitis, K.J., Beck, J.W., Cole, J.E., Dettman, D.L., Peck, J.A., Scholz, C.A. & King, J.W. 2009. Atlantic forcing of persistent drought in West Africa. *Science* 324 # 5925, pp. 377-380.

Skutsch, M., van Laake, P., Zahabu, E., Karky, B.S. & Phartiyal, P. 2009. Community monitoring in REDD+. In: Angelsen, A. ed. *Realising REDD: national strategy and options*. CIFOR, Bogor, Indonesia.

Stadtmüller, T. 1994. *El impacto hidrológico del manejo forestal de bosques naturales tropicales: medidas para mitigarlo*. Una revisión bibliográfica. Serie técnica, informe técnico No. 240, CATIE, Turrialba, Costa Rica.

UNFCCC. 2015. *Adoption of the Paris Agreement*. FCCC/CP/2015/L.9. United Nations Framework Convention on Climate Change (UNFCCC).

Van de Sand, I., J. K. Mwangi, and S. Namirembe. 2014. Can payments for ecosystem services contribute to adaptation to climate change? Insights from a watershed in Kenya. *Ecology and Society* 19(1): 47.

Weber, J.C., Larwanou, M., Abasse, T.A., Kalinganire, A. 2008. Growth and survival of Prosopis africana provenances tested in Niger and related to rainfall gradients in the West African Sahel. *Forest Ecology and Management*, 256:585-592.